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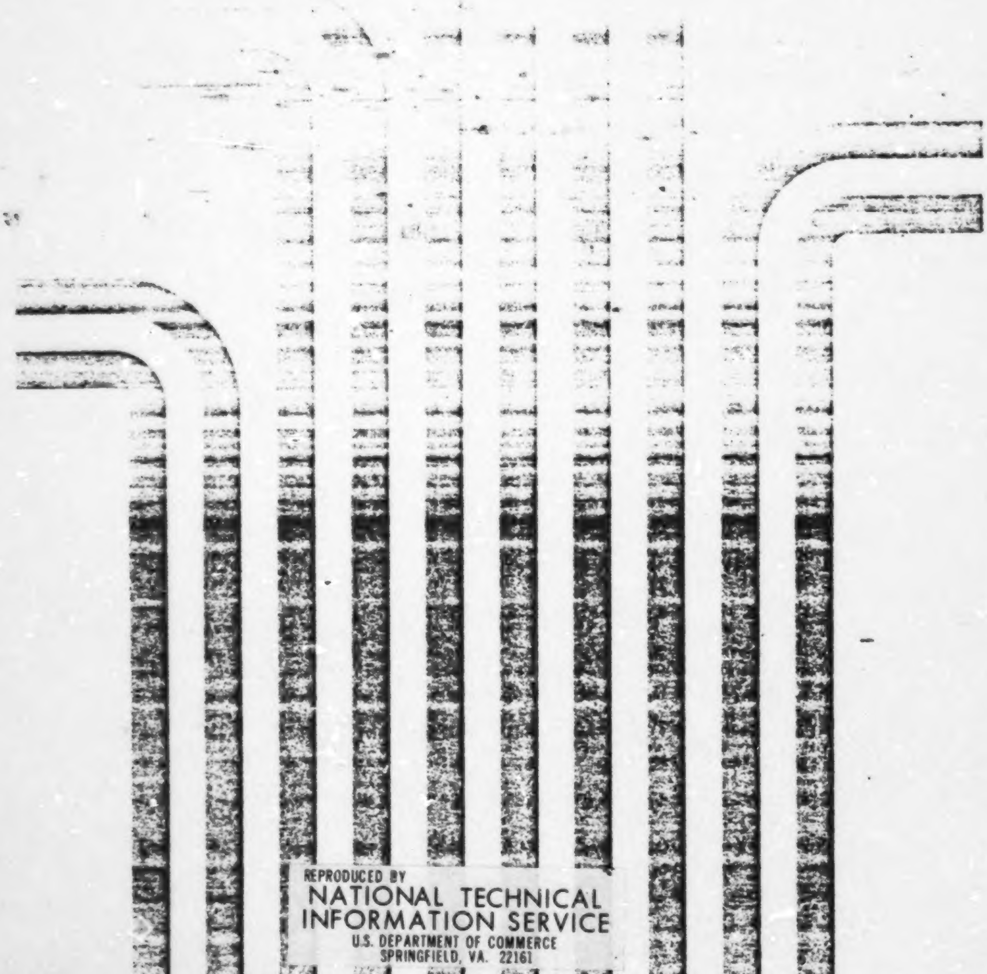

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The results were developed into predictive, planning tools which can be used to estimate urban runoff quality, quantity and receiving water effects. Best Management Practices (BMPs)for runoff control are also discussed along with strategies for assurance of the most effective regional solution. Conclusions, recommendations, and areas requiring further study are discussed in the final chapter.

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DENVER REGION

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This report presents the findings of the three-year Denver Regional Urban Runoff Program. This program studied the nature of urban runoff, its influence on receiving waters, and possibilities for control in the Denver region. Urban runoff characteristics in relation to land use are discussed. The effects of urban runoff on receiving waters are evaluated and compared to municipal discharges over the same time period.

The results were developed into predictive, planning tools which can be used to estimate urban runoff quality, quantity and receiving water effects. Best Management Practices (BMPs) for runoff control are also discussed along with strategies for assurance of the most effective regional solution. Conclusions, recommendations, and areas requiring further study are discussed in the final chapter.

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EXECUTIVE SUMMARY

Urban runoff is one of a number of sources of water pollution referred to as nonpoint sources because of their diffuse nature. The Denver Regional Council of Governments (DRCOG) and the U.S. Environmental Protection Agency (EPA) noted in the mid-70's that nonpoint sources would need to be controlled if the clean water goals of the region and nation were to be obtained. This report presents the conclusions of an intensive effort by DRCOG, with help from a number of agencies, to understand the characteristics of urban runoff and potential control measures in the Denver region.

The 1977 DRCOG Clean Water Plan expressed concern about nonpoint source pollution and suggested that for some pollutants urban runoff exceeded municipal treatment plants as a source. EPA reached the same conclusion after receiving areawide plans from many parts of the country. Congress, in 1978, directed EPA to conduct a National Urban Runoff Program to build upon pertinent prior work and to provide additional pertinent information and insights. DRCOG was selected as one of 28 agencies to participate in this program.

As summarized in this report, DRCOG, with help from the United States Geological Survey, monitored several small basins in the region to determine the characteristics of urban runoff. Also, the South Platte River was sampled both during storms and dry periods to estimate the effect of urban runoff on this major water resource. Based on this information, various tools for predicting urban runoff characteristics were developed. Finally, a number of local governments and the Urban Drainage and Flood Control District tested various options for controlling urban runoff quality. The major findings of these various tasks are outlined below.

RUNOFF CHARACTERISTICS

Urban runoff was monitored from nine urban basins representing various land uses and intensities of development. Runoff was analyzed for 15 constituents of concern along with EPA priority (toxic) pollutants. Concentrations of constituents were calculated and compared to concentrations in secondary wastewater effluent. Concentrations and unit-area loads of constituents were related to land use, basin imperviousness, and hydrologic parameters to determine if relationships existed between these variables. Also, a pervious detention basin was studied as a control measure for reducing runoff pollutant loads.

Average event mean concentrations of total lead and zinc were greater in rainstorm runoff from all basins than secondary wastewater. Concentrations of total copper were greater in runoff from two basins. Most forms of the nutrients monitored, expecially total Kjeldahl nitrogen and total phosphorus, had much greater concentrations in wastewater. Only nitrite-nitrate nitrogen was found in higher concentrations in runoff from several basins.

Very few EPA priority pollutants were detected in runoff samples. Organic pollutants found were particularly sparse, and the most commonly occurring one detected was a pesticide. The most significant non-priority pollutant found was 2,4-D which is a herbicide. Sources of these pollutants include domestic herbicide and pesticide usage and possible improper disposal, though verification of sources was not made.

Pollutant loading per runoff amount was not found to be well related to basin imperviousness or land use. Vague relationships between event mean concentrations and imperviousness were noted, but proved statistically insignificant. Concentrations of pollutants did not vary in a predictable pattern, or to what was anticipated. It was determined that loading was primarily a function of the quantity of runoff generated at a site. The portion of rainfall occurring as runoff was found to be well related to basin imperviousness. As a result, pollutant loading per rainfall amount was related to basin imperviousness.

The detention basin analysis concluded that the one basin studied was effective in reducing loads of certain constituents. It was most effective for reducing loads of metals, chemical oxygen demand, ammonia and dissolved phosphorus. Total suspended solids were not greatly reduced on the average.

EFFECTS ON THE SOUTH PLATTE

A receiving water assessment was included in the program to denote the effects of urban runoff on the major waterbody in the region. The South Platte River is the ultimate receiving water for both wastewater effluent and urban runoff generated within the Denver metropolitan area. Significant amounts of sediment, bacteria, nutrients, organic matter and heavy metals were found to enter the river during storm events compared with discharges from wastewater treatment plants over the same time period.

The investigation of the effect of urban runoff on receiving waters involved three considerations. These were: 1) comparison of pollutant concentrations monitored in the South Platte River during storm events with those occurring during ambient streamflow, 2) comparison of the relative amounts of pollutant loads entering the river from storm runoff with those from municipal wastewater sources, and 3) comparison of pollutant concentrations during periods of storm runoff and ambient streamflow with water quality standards in effect for the study segment of the South Platte River.

Several water quality constituents had mean concentrations greater during storm runoff than during ambient streamflow. Suspended sediment and fecal coliform bacteria exhibited much greater concentrations during storm events, as did oxygen-demanding substances and heavy metals. Total metals concentrations for lead, zinc, copper, cadmium, iron and manganese during storm-runoff periods were greater than mean ambient concentrations and exceeded established stream standards 100 percent of the time. Effective control of urban runoff to reduce the concentration of these constituents would improve the quality of water of the South Platte River.

Concentrations of nitrite, nitrate and un-ionized ammonia did not exceed stream standards during storm periods and will not pose problems for aquatic life. Monitoring data indicated temperature, pH and dissolved oxygen limits were never exceeded during either storm or ambient periods. Fecal coliform bacteria exceeded the standard 31 percent of the time during ambient streamflow and 100 percent of the during storm periods. Un-ionized ammonia also exceeded the standard 31 percent of the time during ambient conditions but, due to the effect of dilution, did not exceed the standard during storms. The levels of bacteria and un-ionized ammonia occurring during low-flow conditions should be considered further as to their effect on maintaining beneficial uses of the river.

A comparison of the relative loading from point sources, baseflow and urban runoff was necessary to denote the effects of urban runoff on the South Platte River. Results indicated that municipal wastewater discharges contributed the greatest amount of nitrogen, phosphorus, and organic carbon to the river on an annual basis. Total suspended solids and lead loading were shown to be predominantly influenced by contributions from urban runoff.

The effects of urban runoff on beneficial uses are difficult to quantify. Effects tend to relate more to the protection of the fishery. Recreational effects are considered to be minimal since little recreation occurs during storm events. High concentrations of sediment, bacteria and dissolved metals in urban runoff should be considered as to their effect on the fishery status of the South Platte River and downstream withdrawals of water for municipal and agricultural uses.

PREDICTING URBAN RUNOFF CHARACTERISTICS

The relationships described above were developed into models which can be used to predict urban runoff characteristics and effects on the South Platte River and its tributaries. Information gathered from these models may be useful in storm water management plans for a preliminary evaluation of the effects of urban runoff on water quality.

Relationships between rainfall, runoff, unit-area loading and basin characteristics were developed into a nomograph and figures which can be used to predict urban runoff quantity and quality from small urban basins with specified characteristics. The use and limitations of these models are discussed, along with several practical examples. These models are easy to use and can provide reasonable estimates of runoff quantity and quality based upon rainfall and land use. Results from them are suitable for planning-level analysis.

Three methods were presented for predicting receiving water characteristics: 1) regression equations relating loading to streamflow, 2) an empirical method of extrapolating the small basin models to the larger South Platte River Basin, and 3) a computer-based water quality model. Results from the first two methods were compared to measured data and were concluded to be within a reasonable margin of error. The last method described is the use of Hydrologic Simulation Program - FORTRAN (HSPF) to predict receiving water characteristics. This effort is currently in the hydrologic calibration phase. Once completed, this model will be used in planning efforts.

Both of the first two methods described to predict receiving water characteristics employ regression equations with few variables required. A disadvantage of using the equations for relating storm flow to loads is that information on storm volume in cubic feet is required. A drawback of using the empirical method of extrapolating small basin models to large basins such as the South Platte River is that this procedure fails to account for the numerous factors and processes which determine receiving water loads going from small sites to large basins.

The final prediction tool developed in the program uses weather radar to estimate the spatial and temporal distribution of rainfall within the DRURP study area. Radar intensity information was ground-truthed to a network of raingages, and curvilinear relationships were derived which were used to predict rainfall amounts. Another element of the weather radar involved the identification of preferred thunderstorm tracks in the Denver area.

It was concluded that it is possible to define the spatial and temporal distribution of rainfall through weather radar. However, much more research is needed to produce accurate maps of expected rainfall in the region. It was also concluded that both north and south preferred thunderstorm tracks do exist in the study area. Areas beneath these tracks are more likely to receive intense rainfall from thunderstorms.

It was hoped that the radar information could be used to define urban runoff control priority areas to provide a method for allocating limited funding to high intensity areas. While potentially useful, radar mapping needs a much larger data base before areas of greater rainfall can be determined. Instead, priority areas were based on other characteristics, especially the amount of construction activity. A hierarchy of control areas is described beginning with areas experiencing urbanization and continuing to areas undergoing redevelopment, areas containing existing detention structures, areas where new flood control structures are being installed, and areas of greatest runoff potential as determined by degree of development. It is expected that water bodies would experience the most benefit if control of urban runoff followed this sequence.

MANAGING URBAN RUNOFF

The issue for an area such as the Denver region is whether or not it is cost-effective to develop an urban runoff quality control program. The DRURP did conclude that certain pollutants may be present in runoff in sufficient quantities to exceed stream standards. Therefore, it may be more cost-effective to control nonpoint sources rather than upgrade wastewater treatment plants to achieve the same stream standard.

Managing urban runoff can be accomplished by implementing structural and nonstructural Best Management Practices (BMPs) at the local government level. During the three-year DRURP, Adams County, the City of Englewood, and the City of Littleton participated in a Model Implementation Program, where site-specific control measures were developed, followed by a program to implement the results. The three local governments focused on either effect-oriented structural controls or cause-oriented nonstructural controls.

Detention was found to be an effective structural control for removing pollutants such as total phosphorus, lead, zinc, and total nitrogen. Costs of detention range from $200-$400 per acre of drainage area. Another form of detention, percolation pits, was investigated by Adams County. These pits remove pollutants by capturing runoff and filtering it through substrate soils. Costs of percolation pits are estimated to be $5,600 per impervious acre for one-half inch of runoff. The City of Englewood found detention basins followed by infiltration pits to be the most cost-effective control measure for removing pollutants in runoff in order to protect McLellan Reservoir. The cost of this system was estimated to be $1 million, which is less than the cost of diverting the runoff around the reservoir via a pipeline.

Nonstructural controls such as ordinances and maintenance of existing drainage facilities can help to control sediment carried in urban runoff. The City of Littleton investigated these two nonstructural control measures and determined them to be effective. Maintenance of drainage facilities would reduce flooding problems and allow for proper conveyance of stormwater, thus eliminating sediment accumulation and providing better detention. The cost for a maintenance program would range from $150,000 to $200,000 annually. An erosion control program for the City would cost $5,000 and $10,000 annually. Such a program would control sediment from construciton sites, thereby reducing pollutants attached to the sediment.

CONCLUSION AND RECOMMENDATIONS

The three-year DRURP effort has been an attempt to quantify urban runoff effects on water quality in the Denver area. Much has been learned and areas where additional research is needed have been identified. A number of recommendations are made concerning control of the region's runoff and the need for additional research.

The study has shown that urban runoff is a significant source of some water pollutants. The most obvious pollutant is total suspended solids. This was true regardless of the existence of major land disturbances causing erosion. Urban runoff was also a significant source of fecal coliform bacteria, oxygen demanding substances, and metals during storms. In addition, nutrients from urban runoff are and will be a problem for lakes and reservoirs.

Non-storm urban runoff was also identified as a source of pollutants. This was not expected and was determined indirectly in the study analysis. This should be investigated directly to evaluate the magnitude of this source of pollution and methods for its control.

The DRURP did evaluate two control measures for urban runoff quality and found both to provide benefits. Detention basins and percolation pits can both be effective. With this information and some recommendations on priorities, the following steps should be taken to begin an urban runoff quality control program:

- existing detention ponds throughout the region, but especially in highly developed areas, should be modified to improve their performance as treatment mechanisms;

- urban runoff quality control should be coordinated with urban flooding control. This may mean expanding the responsibilities of the Urban Drainage and Flood Control District to include quality as well as quantity. Such a change may require legislative action. However, examples of quantity and quality agencies exist in other NURP projects such as Salt Lake County, Utah and Bellevue, Washington;

- local governments should pursue implementation of drainage ordinances that incorporate water quality aspects. This may include detention design, percolation pits and erosion control;

- a central element of local implementation projects is interdepartmental coordination between planning, engineering and building departments. Without such coordination, no drainage improvement program will be successful; and,

- continued maintenance of drainage facilities is needed to achieve optimum performance. A detention basin will not function when accumulated sediment is not regularly removed.

The implementation of these actions will not totally control pollution from urban runoff. It will represent an initial step toward the elimination of a significant source of pollutants.

This study has not answered every question about urban runoff, and in some cases, the answers presented have led to new questions. To more fully understand urban runoff, the following issues should be addressed:

- detention basin characteristics. This study was not able to explore, as thoroughly as originally anticipated, the ability of detention basins to remove pollutants. Various types of detention need to be tested such as wet versus dry ponds. Outlet modifications need to be studied to determine optimum design. Size requirements and holding times should be developed into design criteria;

- impact assessment. While the DRURP has demonstrated that urban runoff causes stream standards to be violated, the actual impact on beneficial uses has not been determined. Do the elevated levels of total suspended solids and various metals during and after a storm harm aquatic life? Are recreational and water supply uses impaired because of storm runoff? Questions such as these need to be dealt with before major implementation costs are incurred;

- point/nonpoint tradeoffs. The concept of nonpoint source control as a replacement for advanced waste treatment at a domestic or industrial plant has only been touched upon in this report. This topic should continue to receive attention so that it can become a normal element of facility planning; and

- trickle flows. It became obvious during preparation of this report that stormwater is not the only source of urban runoff. The daily flows into the region's streams from urban areas due to lawn watering, car washing, and other activities in some cases are significant contributors of pollutants. This may mean that point-source treatment and stormwater control together may still not achieve water quality goals. This is a significant, new element of the pollution control equation. More information is needed about the quality of this dry-weather trickle flow, the sources of the pollutants within this flow and any methods for control.

After three years of study and evaluation, the Denver area now has a better understanding of urban runoff. While more questions exist, enough is known to begin controlling the quality of urban runoff. The suggestions made here for implementation and further study will enable the area to move one step closer to meeting its water quality goals.

I. INTRODUCTION

"A basic premise of (water-quality) planning is that the goal of fishable/swimable water is not attainable unless both point source and nonpoint source pollution are considered in future abatement plans. Nonpoint sources of pollution can, during high runoff periods, contribute a much larger pollutant loading to area streams than point sources."[1]

This statement from the Technical Report to the DRCOG Clean Water Plan expressed the concern in 1977 that control of point source pollution alone might not result in consistently high quality water in the area's streams, rivers, and lakes.

This report presents the results of a three year study of one nonpoint source, urban runoff, and confirms the concern expressed in 1977 that urban runoff is a significant source of pollutants. However, there are methods to deal with urban runoff within the study area which may enable tradeoffs between higher levels of municipal wastewater treatment and control of nonpoint sources.

This chapter of the report reviews DRCOG's concern with nonpoint pollution. National concerns presented DRCOG the opportunity to conduct the present study. The scope of work is outlined as originally conceived and as actually conducted.

The following chapters describe the results of the study. Chapter II describes the study area. The characteristics of urban runoff and its effect on the South Platte River are summarized in Chapters III and IV. Chapter V outlines various tools to predict urban runoff effects from land development activities. Methods for managing urban runoff are the subject of Chapter VI while Chapter VII presents a general conclusion to the study.

DRCOG'S INVOLVEMENT IN NONPOINT POLLUTION PLANNING

The original DRCOG Clean Water Plan expressed concern about nonpoint sources of pollution. These are defined as sources of pollutants which enter waterways from diffuse areas rather than through a pipe or similar "point" source. The planning program conducted by DRCOG between 1974 and 1977 under Section 208 of the Federal Clean Water Act contained a major element directed at nonpoint sources.

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[1] DRCOG, Technical Report to the DRCOG Clean Water Program. (Denver, Colorado, 1977). page 6-1.

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The Clean Water Plan listed eight sources of nonpoint pollution: urban runoff, septic tanks, landfills, agriculture, foresting, mining, stream channel modification, and new construction. Each of these sources contributes pollutants to the area streams although each may contribute different pollutants in varying amounts. For example, new construction can result in the stripping of large areas of land which exposes the soil. This can lead to water problems with sediments, oils, and chemicals via rainfall and subsequent runoff.

Comparisons of point sources and nonpoint sources were made in the Clean Water Plan. Pollutants included biochemical oxygen demand (BOD), total dissolved solids (TDS), fecal coliforms, ammonia ($NH3$), nitrate ($NO3$), and phosphate ($PO4$). The plan concluded that with the exception of ammonia ($NH3$) and phosphate ($PO4$), nonpoint sources of pollution dominate point sources.[2] The report suggested that some stream standards could not be achieved through control of point sources alone.

However, these findings and conclusions were based on limited field data and computer modeling. One of the reasons that no major control programs were made a part of the Clean Water Plan was the need for a better understanding of nonpoint sources and their control. As stated in the Plan, "additional data is needed to assure that the model and analysis are accurately representing the impact of nonpoint pollution on water quality. This additional data, which will relate not only to the source but to specific instream water quality impacts, is needed prior to the investment of major financial resources ".[3]

It was because of this perceived need for better information, that DRCOG undertook the Denver Regional Urban Runoff Program (DRURP). While explained in more detail in the remainder of the report, the following major conclusions about urban runoff are:

- For some pollutants, urban runoff is a major contributor;
- Non-storm urban drainage is another major source of pollutants;
- Land use does have an influence on the types and quantities of pollutants; and
- There are a number of Best Management Practices that can reduce urban runoff contributions to stream and lake pollution.

These conclusions were reached through an extensive program. The purposes of this program, both national and regional, are outlined in the next section.

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[2] Ibid., p. 6-6

[3] DRCOG, Clean Water Plan (Denver, Co., 1977), p. 20.

PURPOSE OF THE NATIONAL URBAN RUNOFF PROGRAM

At the national, as well as local level, urban runoff was recognized as a water quality problem. The DRURP was designed to meet both the national and regional objectives.

The national program was based on a growing concern about urban runoff. As early as 1965, the Federal Water Quality Act authorized grants for methods of controlling storm water pollutants. By 1972, Section 208 of the Federal Water Pollution Control Act required state and local water quality planning agencies to include nonpoint sources in their plans. As these plans were developed, uncertainties associated with the local nature and extent of urban runoff water quality problems, the effectiveness of possible management and control measures, and their affordability in terms of benefits to be derived mounted. Because these unknowns were so great, Congress deleted federal funding for the treatment of stormwater discharges from the Clean Water Act of 1977.

In 1978, after reviewing the past work on urban runoff by DRCOG and similar agencies, the U.S. Environmental Protection Agency (EPA) determined that additional data was needed. In response to Congress, EPA initiated its Nationwide Urban Runoff Program (NURP) to build upon pertinent prior work and to provide additional practical information and insights. EPA did not intend the NURP to be a scientific research program, but a practical approach to providing information sufficient to allow planning decisions to be made.

As stated in the EPA report, Preliminary Results of the Nationwide Urban Runoff Program, the primary NURP objective is to develop water quality management plans that will be appropriate, acceptable, affordable, and focused on local needs. This requires information that will allow determination of:

- the extent to which urban runoff is a contributor to water quality problems as compared to other sources and/or background loads,
- the effectiveness of control short of treatment in reducing water quality problems when they exist, and
- whether best management practices for control of urban runoff are cost effective in comparison to alternative options.[a]

The NURP includes 28 separate and distinct planning projects of which the DRURP is one. These projects were selected because they had previously identified urban runoff as one of their significant problems. Also, projects

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[a] U.S. Environmental Protection Agency, Results of the Nationwide Urban Runoff Program (Washington, D.C., 1982, Executive Summary). page 1.

were selected to provide a range of certain characteristics, e.g., hydrologic regimes, land uses, populations, drainage systems, and control measures.

After these project sponsors were identified, EPA worked with local staffs to develop work programs. These work programs were to determine:

- **the nature of urban runoff problems where significant problems have been identified,**
- **the causes of these problems (e.g., sources, transport modes, and impacts),**
- **the severity of these problems, based on consideration of beneficial uses and water quality standards, and**
- opportunities for controlling urban runoff problems, including descriptions of control measures, their effectiveness, costs, and strategies for broad-scale implementation.[5]

EPA will be preparing a national report on NURP at the completion of the 28 projects. This report will be provided to Congress in order to determine what national program in urban runoff should be established. EPA also believes that NURP will be able to provide to local and state governments a data base of urban runoff loading factors, new methods of analysis, and information on control techniques which can be used in dealing with urban runoff problems.

OBJECTIVES OF THE DENVER REGIONAL URBAN RUNOFF PROGRAM

When DRCOG became aware of the EPA nationwide program, it was recognized as an opportunity to address the unanswered question of the Clean Water Plan. Working with two agencies which had assisted DRCOG in nonpoint analysis during preparation of the Clean Water Plan (the U.S. Geological Survey and the Urban Drainage and Flood Control District), DRCOG prepared a work program to meet both the national and areawide objectives.

The principal objectives were defined as:

- **to characterize runoff pollution loadings by land use type. The dearth of data applicable to the Denver area and other semi-arid regions makes the the basic characterization of nonpoint source pollution a primary objective of the program;**
- **identify the specific land surface sources of pollutants;**

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[5] **Ibid, pages 1-2.**

- determine, to the extent possible, the effects of nonpoint source pollution loads on receiving waters;

- determine the technical and institutional opportunities for the control of nonpoint source loads by the implementation of Best Management Practices; and

- determine, through computer model calibration efforts, dry weather surface accumulation rates appropriate for the Denver area. These build-up rates would serve as indicators for other similar semi-arid western urban areas. DRCOG intended to use two models, the Nonpoint Source Pollutant Loading model and the Hydrologic Simulation Program - FORTRAN model.

While these primary objectives were the main focus of the Denver region program, an additional set of secondary objectives were established. These were to address more specialized areas of interest, either locally or to EPA. They included:

- define empirical relationships to facilitate data transferability among urban areas, especially semi-arid areas. This topic is discussed in Chapter V;

- define linkages between air quality and runoff pollution for various urban land uses as well as beneficial impacts of certain nonstructural runoff controls on ambient air quality. While a limited amount of effort was expended on this task, no relationship could be demonstrated;

- determine if preferred moderate-heavy seasonal precipitation regions exist within the urban basin due to repeatable meteorological and topographical influences. The results of the storm monitoring are discussed in Chapters V and VII;

- for various land uses, characterize the relationship between total and soluble pollutant loads. If most pollutants are in soluble form, they cannot be controlled by techniques which rely upon sedimentation. The limited data collected is described in Chapter III;

- determine the effects of dry atmospheric deposition and rainfall pollutant loads on runoff loadings. This data has been collected but not analyzed;

- determine the relationship, if any, between the fractions of pollutant loads associated with discrete particle sizes as found in Denver with similar information from studies ongoing elsewhere. The DRCOG data, collected by USGS, is discussed in Chapter II. No data is yet available from other areas to determine transferability;

- determine the effects of chemical additions on control measure efficiencies through the use of bench scale evaluations. This objective was not pursued;

- determine for various land uses the relationships between "unit area" runoff pollution loads (pounds per acre) and "unit area" sanitary sewage loads, to a degree suitable for the development of simple empirical desk-top water resources planning models. This effort is described in Chapter V;

- explore the validity of the build-up rate concept and the first order pollutant washoff equation. While of scientific interest, this objective was a low priority and addressed in a separate USGS report; and

- determine to the extent feasible the degree to which certain problem toxics are present in runoff from urban areas and in urban area streams. The results of the toxics monitoring are found in Chapter III.

As with any major program, objectives change and are modified as circumstances occur or preliminary results point in new directions. However, the DRURP was able to address the primary objectives in a complete manner, although the results were not always what had been expected. As mentioned above, most secondary objectives were completed or are still being analyzed. These will add to the information obtained in the Denver region about urban runoff.

The final report is structured to follow the primary objectives. After a description of the Denver area and the study basins, the character of urban runoff is described in Chapter III. Its relationship to land use type and density is discussed. The types of pollutants and their relative strengths are described.

Chapter IV examines the effect of urban runoff on the South Platte River. Storm events cause significant changes in the quality of the river. These changes are measured against beneficial uses as determined by State stream standards. Seasonal loads from storm events are compared to wastewater treatment plant contributions and the background quality of the river.

Various predictive tools are discussed in Chapter V. These include the use of radar to track storms and their rainfall. The concept of preferred storm tracks in the region is discussed. Two methods to model urban runoff quality are developed. One is a "desk-top" method for use in local government evaluations. The other is a major computer simulation program which can be used to develop areawide management plans.

Chapter VI describes the control options studied in the DRURP. The focus of this study was on detention basins. This is compared with information from other NURP projects across the country. Summaries of other methods of control are also presented. The three local government Best Management Practice implementation projects are described.

Conclusions and recommendations are presented in Chapter VII. A regional management program and its likely components is described. Remaining unanswered questions about urban runoff suggest further directions for DRCOG and its member jurisdictions.

II. STUDY AREA AND MONITORING PROGRAM DESCRIPTION

Water quality planning activities are conducted by DRCOG for its member governments in Denver, Boulder, Jefferson, Douglas, Adams, and Arapahoe Counties. This six-county region encompases approximately 2.9 million acres (4,530 square miles), of which the DRURP study area comprised only a limited portion (4 percent) of the total and centered around the greater Denver metropolitan area. The purpose of this chapter is to present a detailed description of the study area and describe the three coordinated monitoring programs associated with the study. Information is presented on climate, physiography, hydrology, land use, population, and general basin characteristics. Monitoring sites are identified along with a description of the raingage network which provided information on rainfall throughout the study area in general, and specific rainfall information at each of the urban runoff monitoring basins.

BASIN CHARACTERISTICS

Figure 1 is a map of the study area indicating the instream and tributary monitoring stations. The basin includes approximately 120,000 acres (187 sq. mi.) and is primarily drained by a 14.5 mile reach of the South Platte River. The basin is defined by two U.S. Geological Survey streamflow monitoring stations, the South Platte River at Littleton which defined the upstream boundary, and the South Platte at 50th Avenue in Denver which defined the downstream boundary. The basin included all tributary inflows as well as Cherry Creek below Cherry Creek Dam and Bear Creek below Mount Carbon Dam.

Climate

The climate of the DRURP study area is considered to be semi-arid, with only about 14-15 inches of annual precipitation. Regional precipitation is quite variable. This is characterized by a non-uniform spatial distribution of precipitation, as it is not unusual for one area to receive a large amount of precipitation during a storm while an area just a few miles away will receive substantially less. This spatial distribution often causes significant fluctuation in total precipitation across the DRURP study area. About two-thirds of the annual precipitation is received during the spring and summer months as either: 1) thunderstorms; or, 2) upslope rainstorms. Approximately one-third of the total regional precipitation occurs as snowfall.

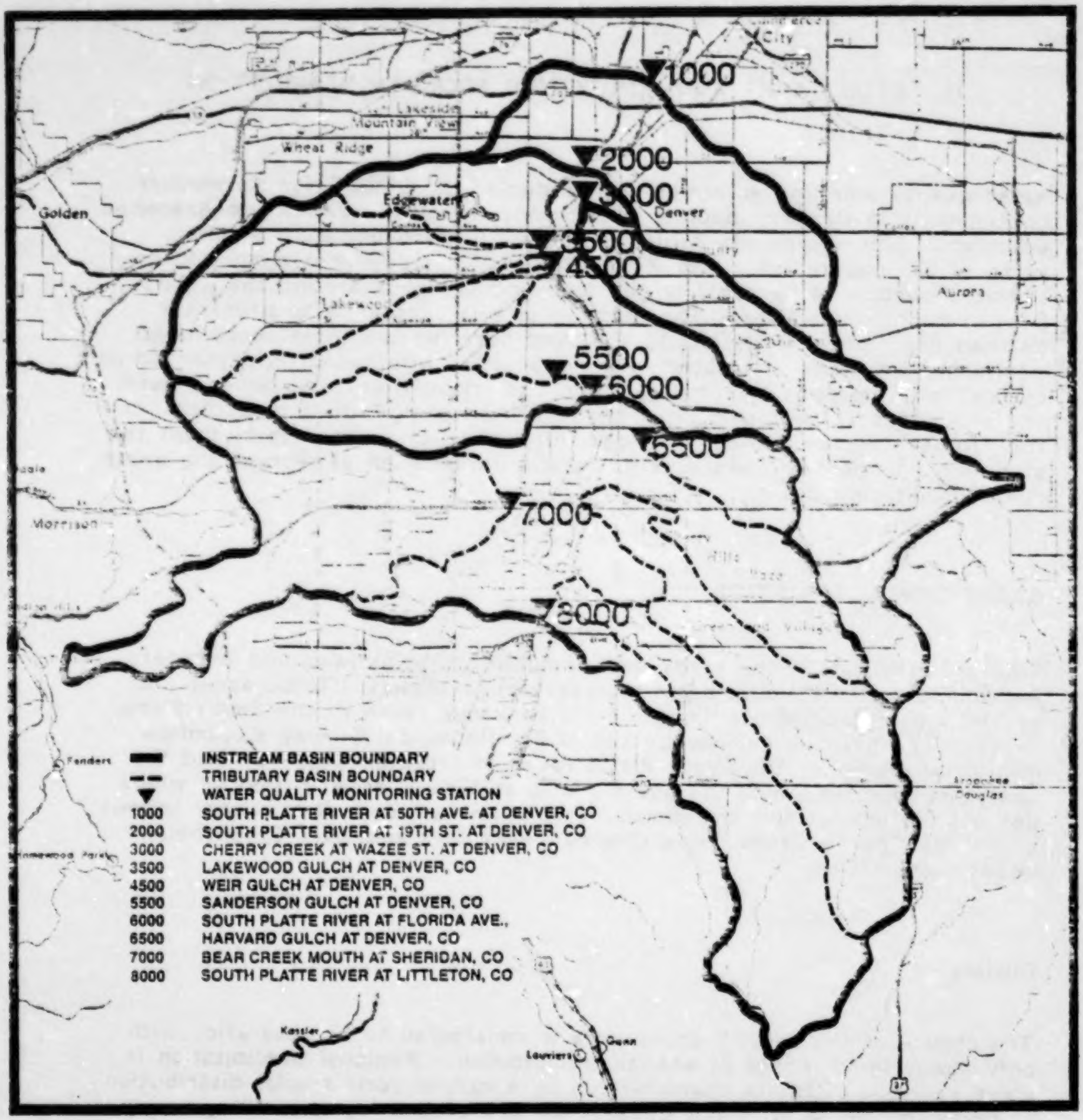

1000
2000
3000
3500
4500
5500
6000
6500
7000
8000
Golden
Edgewater
Wheat Ridge
Mountain View
Lakeside
Commerce City
Denver
Lakewood
Aurora
Morrison
Englewood
Cherry Hills Village
Greenwood Village
Fenders
Kassler
Louviers
Sedalia
INSTREAM BASIN BOUNDARY
TRIBUTARY BASIN BOUNDARY
WATER QUALITY MONITORING STATION
1000 SOUTH PLATTE RIVER AT 50TH AVE. AT DENVER, CO
2000 SOUTH PLATTE RIVER AT 19TH ST. AT DENVER, CO
3000 CHERRY CREEK AT WAZEE ST. AT DENVER, CO
3500 LAKEWOOD GULCH AT DENVER, CO
4500 WEIR GULCH AT DENVER, CO
5500 SANDERSON GULCH AT DENVER, CO
6000 SOUTH PLATTE RIVER AT FLORIDA AVE.,
6500 HARVARD GULCH AT DENVER, CO
7000 BEAR CREEK MOUTH AT SHERIDAN, CO
8000 SOUTH PLATTE RIVER AT LITTLETON, CO

FIGURE 1. MAP OF STUDY AREA SHOWING INSTREAM AND TRIBUTARY BASINS.

Physiography

The DRURP study area is situated in the Piedmont region of Colorado between the Rocky Mountains to the west and the High Plains to the east. Elevation ranges from a maximum of 7965 feet in the foothills along the western boundary and 6580 feet on the eastern side of the basin. The South Platte River flows generally in a northerly direction from about 5310 feet above mean sea level at the Littleton station to about 5140 feet at the downstream 50th Avenue station. The river lies in a broad alluvial flood plain. The channel bottom is mostly sand and gravel except for a few areas of exposed bedrock (Denver formation) or where organic sediment has accumulated.

Hydrology

The South Platte River has experienced wide extremes in streamflow over the past 33 years of streamflow records collected by the U.S. Geological Survey. Extensive flooding has occurred at times, such as in 1965 when a streamflow of 110,000 cubic feet per second (cfs) was recorded at the Littleton gage. Drought years have also occurred during this time interval. For instance, in 1956, the minimum daily flow recorded was 7.2 cfs at the Littleton gage.

Prior to 1975 the average annual streamflow at the Littleton gage was 234 cfs. In 1975, Chatfield Dam was completed by the U.S. Army Corps of Engineers for basin-wide flood control. This dam, located 6.5 miles above the Littleton station, captures excess streamflow to reduce potential floods. Since 1975, the average annual streamflow at the Littleton station has been reduced to 180 cfs. Within the study area, two other flood control structures have been built on Bear Creek and Cherry Creek and serve to capture excess streamflow. All three dams define surface-runoff topographic basin boundaries on the eastern and western sides of the study area.

Land Use

Table 1 provides a tabulation of the distribution of land use within the study area basin. The land use distribution within the entire study area is approximately 43 percent residential, 19 percent commercial and industrial, and 38 percent open space (parks, vacant and agriculture).

Table 1

DISTRIBUTION OF LAND USE WITHIN STUDY AREA BY SUBBASIN[1]

Station (I.D.#)[2]	Single Family	Multi-Family	Commercial	Industrial	Park	Vacant	Agricultural	Basin Area
Bear Creek (7000) (0611700)	4,444 (30)	477 (2)	1,317 (9)	318 (2)	1,428 (10)	6,507 (45)	112 (1)	14,603 (100)
Harvard Gulch (6500) (06711575)	1,838 (865)	192 (7)	459 (16)	38 (1)	267 (9)	39 (2)	0 (0)	2,833 (100)
Unmonitored Area	12,594 (30)	603 (1)	3,404 (8)	1,484 (4)	1,215 (3)	15,523 (38)	6,542 (16)	41,365 (100)
South Platte at Florida Av. (6000) (06711590)	18,876 (32)	1,272 (2)	5,180 (9)	1,840 (3)	2,910 (5)	22,079 (38)	6,654 (11)	58,811 (100)
Sanderson Gulch (5500) (067711610	2,947 (62)	160 (3)	590 (13)	107 (2)	322 (7)	589 (13)	0 (0)	4,715 (100)
Weir Gulch (4500) (06711622	2,781 (58)	321 (7)	455 (10)	54 (1)	587 (12)	534 (11)	54 (1)	4,786 (100)
Lakewood Gulch (3500) (06711800)	5,070 (49)	628 (6)	2,402 (23)	211 (2)	457 (4)	1,672 (16)	0 (0)	10,440 (100)
Cherry Creek (3000) (06713500)	4,629 (29)	1,929 (12)	2,509 (16)	772 (5)	2,314 (15)	3,664 (23)	0 (0)	15,817 (100)
Unmonitored (Area)	6,095 (44)	989 (7)	2,205 (16)	2,612 (19)	1,185 (9)	674 (5)	0 (0)	13,760 (100)
South Platte at 19th St. (2000) (06714000)	40,398 (38)	4,299 (5)	13,341 (12)	5,596 (5)	7,775 (7)	29,212 (27)	6,708 (6)	108,329 (100)
Unmonitored Area	5,230 (44)	1,110 (10)	2,062 (18)	1,585 (14)	950 (8)	634 (6)	0 (0)	11,571 (100)
South Platte at 50th Ave. (1000) (06714130)	45,628 (38)	6,409 (5)	15,403 (13)	7,181 (6)	8,725 (7)	29,846 (25)	6,708 (6)	119,900 (100)

[1] All values are expressed in units of acres, values in parentheses are percent. Definition of land use categories taken from: "Land Use in the Denver Metropolitan Area," Denver Regional Council of Governments, November, 1981.

[2] First station I.D. number refers to DRCOG station identifier used in this report and also used to store water-quality data in EPA's STORET data system, second station I.D. number refers to U.S. Geological Survey downstream order number classification.

Population

The 1980 population within the study area was approximately 582,000. Although the study area comprised only 4 percent of the six-county region's total area, it contained 36 percent of the region's total population. Table 2 provides a breakdown of resident population and average resident population density of the instream and tributary basins. DRCOG has projected the year 2000 population of the six county region to be 2.5 million, which equates to an annual increase of 2.7 percent between 1980 and 2000. Most of this projected growth is expected to occur around the fringes of the greater Denver metropolitan area and outside of the study area basin. Therefore, the 1980 study area population may not change considerably by the year 2000.

Table 2

INSTREAM AND TRIBUTARY BASIN POPULATION AND GROSS DENSITIES

Station	Basin Name	Population (1980)	Gross Density (P/A)[1]
8000	South Platte at Littleton, CO	(upstream boundary)	
7000	Bear Creek at Mouth at Sheridan, CO	42,534	2.91
6500	Harvard Gulch at Denver, CO	21,873	7.72
5500	Sanderson Gulch at Denver, CO	45,116	9.57
4500	Weir Gulch at Denver, CO	36,547	7.64
3500	Lakewood Gulch at Denver, CO	50,461	7.72
3000	Cherry Creek at Denver, CO	98,397	6.22
	Intervening (unmonitored) area	109,650	3.48
2000	South Platte River at 19th St., Denver, CO	464,942	4.29
	Intervening (unmonitoried) area	116,940	10.00
1000	South Platte River at 50th Av., Denver, CO	581,882	4.85

[1] Persons per acre (P/A).

MONITORING

Water quality monitoring within the study area consisted of three coordinated monitoring programs: 1) instream monitoring; 2) tributary monitoring; and, 3) small basin urban runoff monitoring. These three separate programs allowed for an evaluation of loading from urban runoff on receiving waters progressively from its sources to its destinations. Additionally, a network of rain gages was installed to record the amount of rainfall occurring from each monitored storm event.

Instream Monitoring Sites

The instream monitoring program involved collecting ambient and storm-runoff samples at five major stations. These stations were chosen to coincide with streamflow monitoring locations. Table 3 shows the basin area and percent of the total basin area represented by each station. Instream monitoring sites appear on Figure 1.

Table 3

INSTREAM MONITORING SITES

Station	Basin Area (Acres)	(Mi.^{2})	Percent of Total[1]
8000-South Platte at Littleton	upstream	boundary	0
6000-South Platte at Florida Ave.	58,809	91.8	49.1
3000-Cherry Creek at Denver	51,817	24.7	13.2
2000-South Platte at 19th St.	108,329	169.2	76.2
1000-South Platte at 50th Ave.	119,900	187.3	100

[1] Total basin area is defined by drainage area between gaging stations located on the South Platte River at Littleton, Colorado and at 50th Avenue at Denver, Colorado.

The location of these stations allowed for an assessment of the effect of urban runoff on receiving waters. The South Platte River at Littleton provided the upstream boundary condition for assessing the change in water quality between this site and the downstream site on the South Platte at 50th Avenue. The contributing drainage area above the South Platte River at Littleton, Colorado, is 3069 square miles. Because Chatfield Reservoir is located 6.5 miles above the Littleton gage, the effect of stormwater runoff on the South Platte River above this site was considered to be minimal. The tributary and mainstem stations downstream of the Littleton gage provided progressive assessments of cumulative water quality changes to be made as the South Platte flowed downstream. A major tributary, Cherry Creek at Denver, was chosen as a monitoring site due to the heavily urbanized area within its basin. The Cherry Creek basin streamflow, measured at its mouth, could be isolated from the flow of the South Platte River at 19th Street which is immediately downstream of the confluence of Cherry Creek and the South Platte River.

Tributary Monitoring Sites

The U.S. Geological Survey, through a coordinated effort with DRCOG, monitored three storm events at five major tributaries of the South Platte River in the study area. Additionally, monthly ambient sampling was conducted at these five tributaries during 1981. These tributaries were monitored to determine the contribution of baseflow and urban runoff from these individual subbasin areas. Table 1 identifies the tributaries, basin area and land use distribution within each subbasin. Location of the tributary stations appear on Figure 1.

Urban Runoff Monitoring Basins

Nine small urban runoff basins were selected for storm-event monitoring to assess the contribution of urban runoff pollutants by land use. The basins were small in areal extent and seven of the nine had homogeneous land use. Table 4 describes the land use of the nine sites. Locations of the sites within the study area are identified in Figure 2.

Table 4

URBAN RUNOFF MONITORING SITES

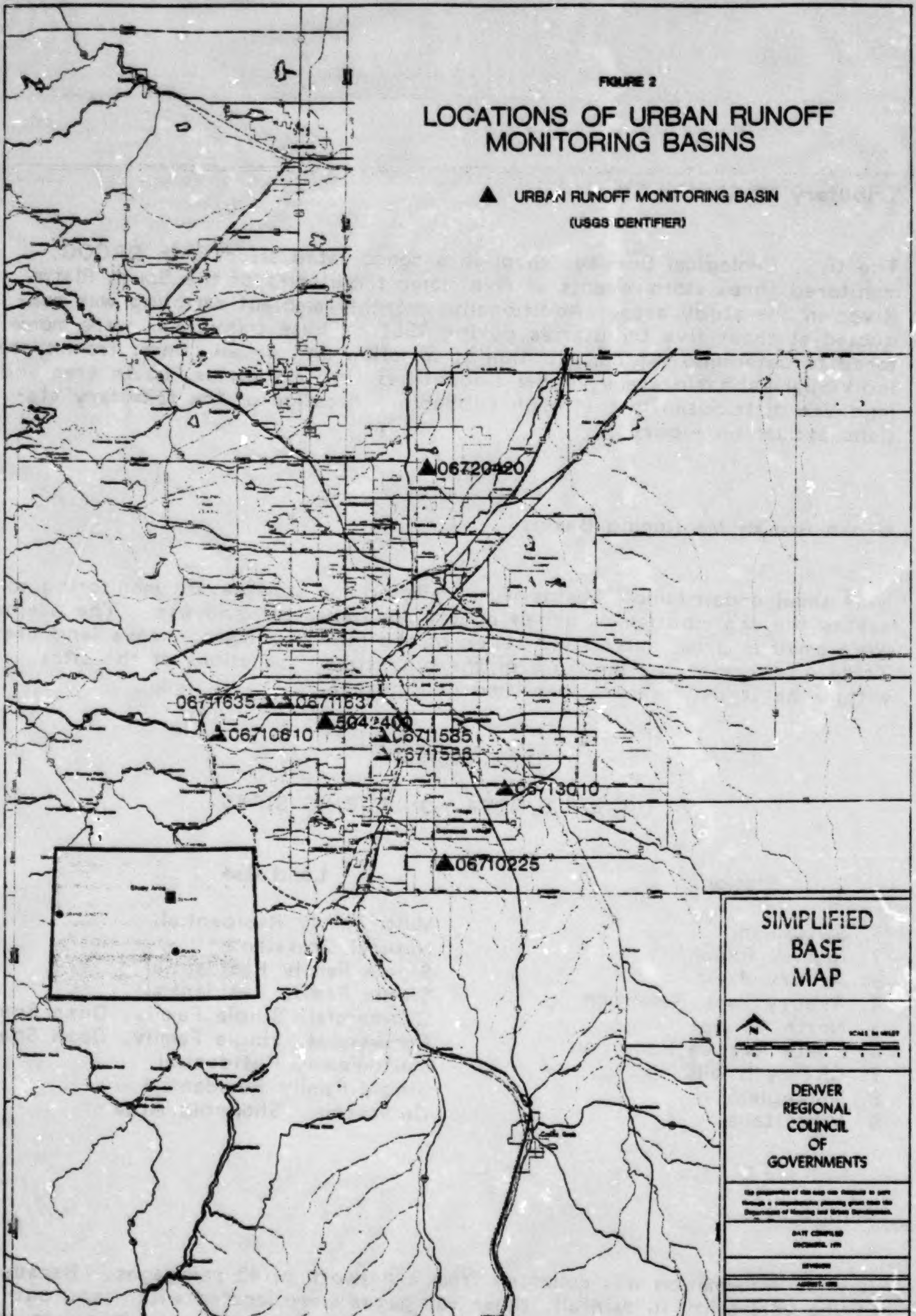
Station	Land Use
1. Southglenn	Multi-Family Residential
2. Rooney Ranch	Natural Grassland
3. Asbury Park	Single Family Residential
4. Asbury Park Retention	Single Family Residential
5. North Avenue	Commercial, Single Family, Open Space
6. North Avenue Retention	Commercial, Single Family, Open Space
7. Cherry Knolls	Multi-Family Residential
8. Northglenn	Single Family Residential
9. Villa Italia	Commercial, Shopping Area

Raingages

Rainfall information was collected from a network of 42 raingages. Because of the variability in rainfall, these raingages were located within and outside of the study area basin. Of these 42 raingages, 19 were in existance prior to the DRURP study. Through the DRURP study, 16 additional gages were installed: Nine at the urban runoff basins and 7 at various locations throughout the region to support the radar precipitation mapping program.

FIGURE 2

LOCATIONS OF URBAN RUNOFF MONITORING BASINS


▲ URBAN RUNOFF MONITORING BASIN
(USGS IDENTIFIER)
06720420
06711635
06711637
5042400
06710610
06711585
06711526
06713010
06710225
SIMPLIFIED BASE MAP
N
SCALE IN MILES
DENVER REGIONAL COUNCIL OF GOVERNMENTS
DRCOG

III. URBAN RUNOFF CHARACTERISTICS

The viewpoint that urban runoff is only a problem in regard to drainage and flood control of cities neglects effects that it may have on surface water quality. Stormwater management planning has primarily been concerned with urban runoff as a quantity problem.

However, urban runoff may significantly affect surface water quality and restrict the beneficial use of lakes and streams for fisheries, water supply and recreational purposes. The problems arise when by-products of everyday activities accumulate on street and other city surfaces, rain loosens and remobilizes these "pollutants", and they are eventually conveyed by gutters and storm sewers to a receiving body of water such as a river. Lead from automobile exhaust, particles of rubber from car tires, and home lawn fertilizers are examples of materials and their sources that may be found in urban runoff. Some of these substances are toxic to aquatic life and humans in high enough concentrations or sufficient exposure.

In an effort to specifically quantify urban runoff pollution in the DRURP Study Area, the United States Geological Survey (USGS) and DRCOG monitored rainfall, runoff and water quality from the nine urban basins described in Chapter II which are representative of various land uses. Runoff characteristics and differences between basins were emphasized. Characteristics such as basin land use and impervious area were examined in an attempt to explain these differences.

A dry, pervious detention basin located in one basin allowed for the study of the effects of this control measure on water quality. Also, in cooperation with the Environmental Protection Agency's (EPA) Office of Water Regulations and Standards, urban runoff from several of the basins was analyzed for EPA "Priority Pollutants" to determine their presence in urban runoff in the region. "Priority Pollutants" refers to the 129 toxic substances derived by EPA and listed in the consent agreement from the court case of the Natural Resources Defense Council versus Train. [1]These samples were also analyzed for EPA "non-priority pollutants" which are additional synthetic organic compounds and major pollutants from industrial sources. This study element was built into two-thirds of (19 of 28) participating NURP projects.

Several other special studies were undertaken in the urban runoff monitoring program. These were conducted with the assumption that their results would assist with understanding of the runoff data. The first of these was an analysis of total versus dissolved forms of metals in runoff samples. A similar analysis was done on nutrients using instream data. Another study evaluated the adsorbtion of metals and nutrients on particle size classes. A vacuum strip sampling study was also done to evaluate pollutant accumulation rates on street surfaces. The final special study dealt with differences between wet fall and dry fall atmospheric deposition rates. Data and preliminary results of these studies are available through DRCOG, but have not been published as of the time of printing of this report.

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[1] Natural Resources Defense Council v. Train, 8 ERC 2120 (D.D.C. 1976).

Results of the urban runoff monitoring study were developed into several predictive models that can be used by local water quality planners and others to estimate the effects of urban runoff on surface water quality and quantity based upon land use (Chapter V). Hopefully, this information will also prove useful in local stormwater management programs concerned with urban runoff quality.

THE RUNOFF MONITORING PROGRAM

Seven urban basins (Figure 2) composed of a single type of land use, and two of mixed land use were monitored by the USGS over a two-year period. Two of these basins represented sites below detention ponds and their basin characteristics were only slightly different from those of corresponding basins with sites above a detention pond.

The basins were mapped from low-level aerial photographs and their percent effective imperviousness (PEI) and area in acres calculated. Effective imperviousness is defined as that portion of the impervious area that contributes directly to surface runoff and is connected to any conveyance structure. A roof with a downspout draining onto a driveway, connected to a street surface, gutter and storm sewer is an example of an effectively impervious area. A roof with a downspout draining onto a grassy area would not be effectively impervious. Basin names, characteristics and locations are contained in Table 5. Further descriptions of the urban basins can be found in the report entitled "Hydrologic Data for Urban Storm Runoff from Nine Sites in the Denver Metropolitan Area, Colorado."[2]

Water-quality samples, rainfall and discharge measurements were taken at five-minute intervals at all sites except Rooney Ranch; Rooney Ranch information was collected every fifteen minutes. All water-quality samples were handled under stringent quality control standards and were analyzed by the USGS Central Laboratory in Denver for the constituents listed in Table 6.

To assist with runoff sampling and pollutant load calculation methodologies, both discrete and composite samples were taken from each basin for the first several storms monitored. Discrete sampling involved the taking of individual runoff samples at intervals throughout the storm's duration,

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[2] Johnnie W. Gibbs, "Hydrologic Data for Urban Storm Runoff from Nine Sites in the Denver Metropolitan Area, Colorado." United States Geological Survey, Open File report 81-682, 1981.

Table 5

DESCRIPTIONS OF URBAN RUNOFF
MONITORING BASINS

Basin Name and USGS Station Identifier	Monitoring Site	Latitude/ Longitude	Land Use	PEI[2]	Ia[3]	Drainage Area (acres)
SOUTHGLENN 06710225	Big Dry Creek Tributary at Easter St. near Littleton, CO.	39 35'17" 104 57'20"	Multi-Family	41.3	[1]	33.0
ROONEY RANCH 06710610	Rooney Gulch at Rooney Ranch near Morrison, CO	39 41'27" 105 11'32"	Natural grassland	0.6	0.6	405
ASBURY PARK[4] 06711585	Asbury Park Storm Drain at Tejon St., Denver, CO	39 40'52" 105 00'42"	Single Family	22.2	32.2	121
ASBURY PARK RETENTION 06711586	Asbury Park Storm Drain at Asbury Avenue, Denver, CO	39 40'51" 105 00'41"	Single Family	21.5	31.3	127
NORTH AVE. 06711635	Upper N. Ave. Storm Drain at Denver Fed. Center Lakewood, CO.	39 43'21" 105 07'47"	Mixed: commercial Multi-Family	50.0	59.9	69
NORTH AVE. RETENTION 06711637	Lower N. Ave. Storm Drain At Denver Fed. Center Lakewood, CO.	39 43'22" 105 07'46"	Mixed: commercial Multi-family	46.0	54.7	80
CHERRY KNOLLS 06713010	Cherry Knolls Storm Drain Denver, CO.	39 38'58" 104 52'47"	Multi-family	37.5	63.6	57
NORTHGLENN 06720420	116th & Claude Ct. Storm Drain, Northglenn, CO	39 54'23" 105 57'34"	Single Family	23.9	37.3	167
VILLA ITALIA 394236105042400	Villa Italia Shopping Center Storm Drain Lakewood, CO	39 42'36" 105 04'24"	Commercial shopping area	91.2	91.2	74

[1] Not calculated
[2] Percent Effectively Impervious Area (see text for explaination)
[3] Percent Impervious Area
[4] Only one storm monitored at basin

analysis of each sample, and calculation of storm loads with each sample representing a portion of the total storm. Discrete sampling entails multiple runoff sample analyses. Composite samples were taken where runoff samples from intervals throughout the entire storm were combined to create a single composite sample based upon each sample's proportion of maximum storm flow. This single composite sample was analyzed and pollutant loads calculated from it. No significant difference between calculated loads was found between these two sampling schemes. As composite sampling only involves one laboratory analysis, this methodology was chosen for later storms so as to maximize information for cost.

Table 6

CONSTITUENTS OF URBAN RUNOFF
ANALYZED IN SAMPLES

NUTRIENTS	Total Phosphorus (TP) Dissolved Phosphorus (DP) Ortho-Phosphate (OPO4) Total Nitrogen (TN) Total Kjeldahl Nitrogen (TKN) Ammonia (NH3-N dissolved) Nitrite-Nitrate Nitrogen (NO2NO3-N)
METALS	Total Lead (Pb) Total Zinc (Zn) Total Copper (Cu) Total Managanese (Mn)
OXYGEN DEMANDING SUBSTANCES AND SOLIDS	Total Suspended Solids (TSS) Total Organic Carbon (TOC) Dissolved Organic carbon (DOC) Chemical Oxygen Demand (COD)

Urban runoff was monitored from three types of storms: thunderstorms, upslope rainstorms and snowstorms. The characteristics and relative importance of these storm types in the DRURP study area were discussed in Chapter II. Data from thunderstorms and upslope rainstorms were combined in the following analyses. Due to the difficulty in quantifying precipitation amounts from snowstorms, few of these were sampled. As a result, only rough comparisons between snowmelts and both rainstorm types are possible.

The primary objectives of the urban runoff monitoring study were to:

1. Characterize the composition and relative magnitude of pollutants measured (Table 6) in urban runoff in the DRURP study area;
2. Define differences in runoff characteristics between basins and relate these to land use and basin PEI;
3. Develop relationships between measured rainfall and runoff at each basin;
4. Combine the results of objectives 2 and 3 to develop simple desk-top models that predict runoff quantity and quality based upon either land use or basin PEI;
5. Evaluate the effects of detention as a "Best Management Practice" for reducing urban runoff pollution.

RAINFALL/RUNOFF RELATIONSHIPS

An estimate of runoff quantity for a given amount of precipitation and specific land use can be important information for use in regional stormwater management plans. Knowledge of differences in expected runoff resulting from changes in land use may prove useful in an assessment of the impacts of development on hydrologic features such as nearby channels and ponds.

Runoff was found to be significantly related to rainfall at each basin. Curvilinear equations were darived between rainfall and runoff at each basin and were used to predict runoff amounts from selected precipitation levels from 0.1 to 2.5 inches. This range of precipitation was chosen as it encompasses the majority of rainfall events in the DRURP study area.

Predicted runoff amounts from the same precipitation level were then regressed against PEI at each basin. Linear equations described this relationship best and were graphed (Figure 3) to provide a means of estimating runoff from rainfall based upon either land use or site PEI.

Due to the limited number and range of storms measured, several restrictions apply to the use of Figure 3. These are discussed in the section entitled "Estimation of Urban Runoff Volume and Pollutants" in Chapter V.

Figure 3 demonstrates that for a given amount of precipitation distributed over an area, runoff will increase as PEI increases. Less of the rain is able to naturally soak into the ground and be intercepted by vegetation as soils and plants are replaced by pavement or other impervious surfaces. A greater portion of it runs off into a gutter, storm sewer, then to receiving waters. Possible data errors and limitations, losses due to evaporation,

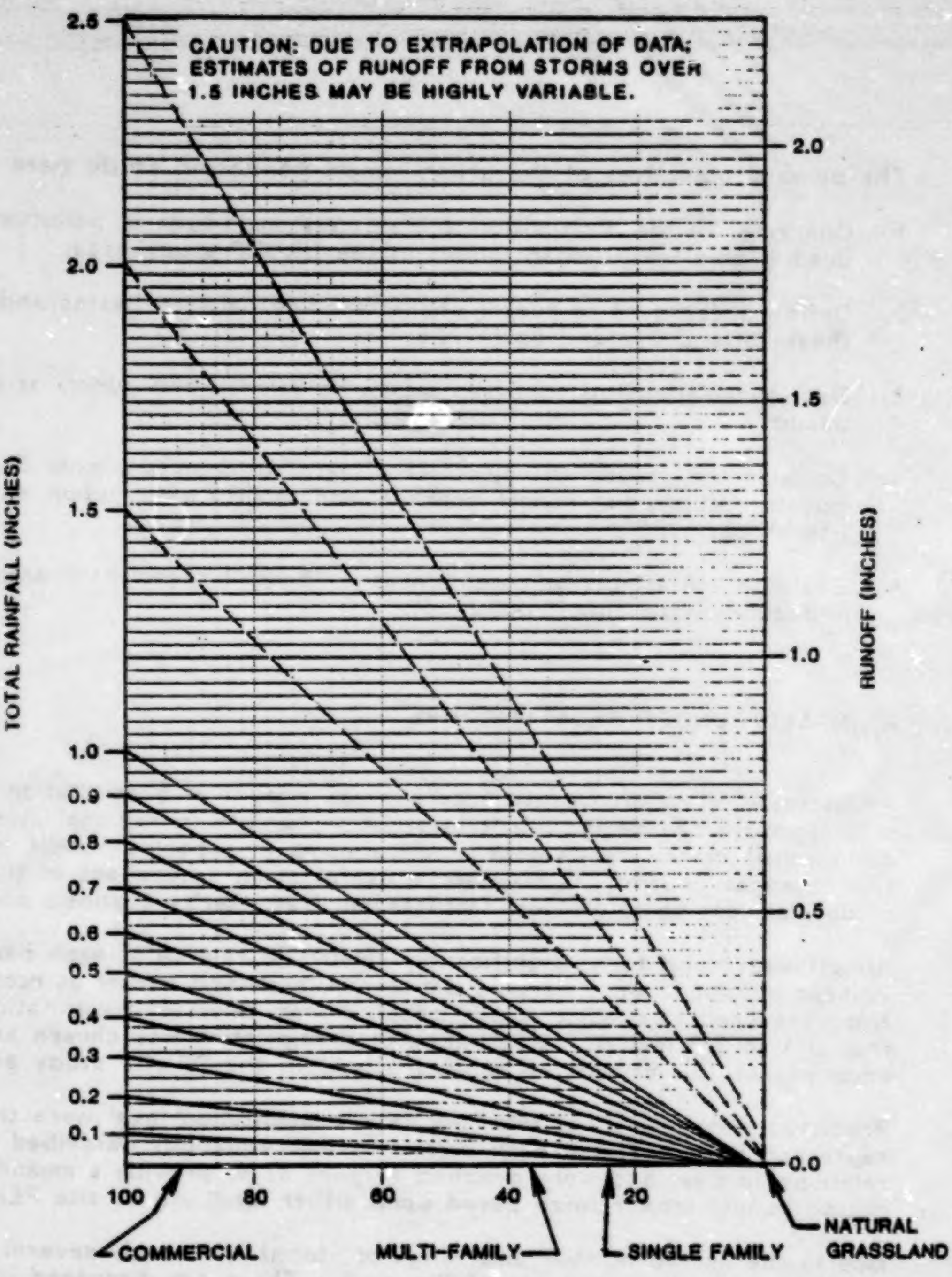

FIGURE 3. NOMOGRAPH FOR ESTIMATING RAINSTORM RUNOFF BASED UPON LAND USE OR PERCENT EFFECTIVE IMPERVIOUSNESS. (SEE TEXT FOR DISCUSSION OF USE, LIMITATIONS.)

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[1] LAND USES CORRESPOND TO PEIs OF URBAN BASINS MONITORED IN THIS STUDY.

surface wetting, and pooling of water along the runoff conveyance network may explain why runoff is less than rainfall at PEI = 100.

At the other extreme, it can be noted that for undeveloped areas with PEI = 0, no runoff will be formed during rainstorms of less 1.5 inches. Infiltration of rain into soils, evaporation, and interception by vegetation partially explain why no runoff is formed from small storms from sites of low PEI. Additionally, runoff formation from such areas is highly dependent upon existing soil moisture conditions. Runoff was produced on the natural grassland basin monitored (Rooney Ranch) from as small as a quarter-inch rainstorm with saturated soils, however, on the average much larger rains were required to produce runoff from this basin.

Figure 3 should be useful to land use planners, water quality engineers and others in the DRURP study area as it predicts probable amounts of runoff from rain depending upon PEI or land use. It should be kept in mind, however, that this figure is not intended to replace other more standard means of runoff volume estimation for engineering purposes. Its use should be restricted to local planning level analysis. Detailed use of Figure 3 and practical examples are presented in the section on predicting urban runoff characteristics in Chapter V.

URBAN RUNOFF POLLUTANTS

Runoff from urban areas contains a complex mixture of nutrients, metals, organic materials, suspended solids and other trace substances. Small quantities of some of these substances are present in precipitation. Other sources of runoff pollutants include: atmospheric dryfall, leaf litter and grass clippings, by-products of combustion of automobile fuels, road salt (during winter months) and domestic fertilizers. Rain washes the accumulated load of such matarials from roofs, sidewalks, streets, parking lots and other surfaces into storm sewers draining into a water body.

The precise nature of urban runoff for a basin may vary depending upon land use. For example, increased amounts of nutrients such as nitrogen and phosphorus would be expected to be found in a drainage ditch serving a residential area. Or, higher amounts of lead (a by-product of combustion of gasoline) would be anticipated in urban runoff coming from a basin with a higher density of streets and parking lots.

Significant amounts of metals, nutrients, suspended solids and the other pollutants monitored were found in urban runoff from all sites. Event mean concentrations of pollutants were calculated by dividing individual storm loads (in pounds) by individual storm runoff (in cubic feet) and converting the result to milligrams per liter (mg/L.). The EMCs for all storms at each station were averaged and are presented in Table 7.

Table 7

AVERAGE EVENT MEAN CONCENTRATIONS (EMC) IN MG/LITER OF CONSTITUENTS MONITORED AT URBAN BASINS[1]

Constituent[2]	5042400 Villa Italia	6711635 North Ave.	6711637 North Ave. Retention	6710225 Southglenn
TP	0.9	0.8	1.4	0.7
DP	0.3	0.2	0.7	0.2
OPO4	0.3	0.3	0.4	0.3
TN	5.5	5.9	8.5	2.7
TKN	4.1	4.5	5.8	2.8
NH3N	1.4	1.2	0.7	0.7
NO2NO3-N	1.4	1.8	1.3	0.6
Pb	0.2	0.3	0.3	0.2
Zn	0.3	0.6	0.5	0.2
Cu	0.04	0.09	0.05	0.04
Mn	0.3	0.5	0.4	0.3
COD	190	330	300	130
TOC	40	72	51	26
DOC	30	41	23	12
TSS	270	470	330	400

Constituent[2]	6713010 Cherry Knolls	6720420 Northglenn	6711586 Asbury Park Retention	6710610 Rooney Ranch
TP	0.4	0.7	1.1	0.4
DP	0.2	0.2	0.2	0.1
OPO4	0.2	0.2	0.3	0.1
TN	3.4	4.3	4.4	3.4
TKN	2.7	3.2	3.7	2.9
NH3N	0.9	0.7	0.7	0.1
NO2NO3-N	0.7	0.7	0.9	0.5
Pb	0.2	0.3	0.4	0.1
Zn	0.2	0.2	0.4	0.1
Cu	0.02	0.03	0.06	0.04
Mn	0.1	0.2	0.6	0.5
COD	130	150	230	72
TOC	22	27	48	26
DOC	12	13	15	16
TSS	180	420	520	400

[1] Averages are not flow-weighted.
[2] Abbreviations are listed in Table 6.

Average EMCs were compared to concentrations of pollutants in secondary wastewater effluent. Because concentrations of pollutants, and especially metals, are variable between wastewater treatment plants depending upon factors such as the amount of industrial flows treated at a facility, data for pollutants were used from the Metropolitan Denver Sewage Disposal District No. 1 (MDSDD#1). This plant treats the majority of wastewater generated in the DRURP study area. Average concentrations and maximum and minimum values of metals and nutrients in effluent from MDSDD#1 appear in Table 8.

Average concentrations of total lead and zinc in effluent were exceeded on the average at all urban basins (Table 7). Average event mean concentrations of total copper were greater from Asbury Park Retention and North Avenue basins than average concentrations in wastewater effluent.

Average concentrations of the nutrients in Table 8 were usually greater than average EMCs from urban basins. Concentrations of total Kjeldahl nitrogen and total phosphorus in effluent were much greater than concentrations in urban runoff. Minimum effluent concentrations of these nutrients were greater than the highest concentration found at any urban basin (Table 7). Nitrite-Nitrate Nitrogen was the only nutrient compared that had higher concentrations in urban runoff from several basins than in effluent.

Table 8

AVERAGE CONCENTRATIONS (MG/L) OF SELECTED POLLUTANTS IN EFFLUENT FROM MDSDD#1[1]

Pollutant	Average Concentration		Range	
METALS:				
Total lead	0.018		0.005-0.059	
Total zinc	0.089		0.076-0.125	
Total copper	0.046		0.024-0.066	
NUTRIENTS:[2]	North	South	North	South
Total Kjeldahl Nitrogen	17.00	23.00	8.90-31.50	14.30-31.00
Nitrite-Nitrate Nitrogen	0.79	0.70	0.01- 3.36	0.01- 0.89
Total phosphorus	3.48	6.18	0.83-7.41	2.82-9.43

[1] Data gathered by verbal communication. Reporting period from January through November 1982.

[2] Nutrient data reported separately for north and south discharge locations.

Snowmelts

Few snowmelt events were sampled in the urban runoff monitoring program and no single snowstorm was monitored at all the basins. With the incomplete and inconsistent data collected, only rough comparisons are possible between runoff data from snowstorms and both rainstorm types sampled.

Average EMCs for snowstorms were calculated for the fifteen constituents measured using the same procedure outlined in the previous section for the following basins that had sufficient data: Villa Italia, Southglenn, North Avenue, North Avenue Retention, and Northglenn. Average snowmelt EMCs were less than those for rainstorms for most constituents at the previously listed basins. Increases were found for the following: total suspended solids at North Avenue Retention, total lead at North Avenue, and total lead and manganese at Southglenn. Very few decreases in average EMC were found to be statistically significant. Those that were are: dissolved phosporus and nitrite-nitrate nitrogen at Southglenn, and total suspended solids and nitrite-nitrate nitrogen at North Avenue.

Greater loading of urban runoff pollutants from rainstorms was probably due to raindrop impact: raindrops contain a substantial amount of kinetic energy that remobilizes and loosens pollutants on an impervious surface such as a street. The impact of snowflakes striking a surface is substantially less.

Priority Pollutants

Very few EPA priority pollutants were detected among the five stations and two storms sampled. Pollutants found are listed in Table 9. The inorganic fractions showed lead, zinc and copper as the most commonly occurring (and most concentrated) components. Arsenic, chromium, nickel and selenium were also found but less frequently and at lower levels. Cyanide was detected at North Avenue and Villa Italia. Possible sources of these pollutants are varied. Lead and Cyanide are by-products of gasoline combustion, and zinc is a component of automobile tires. Arsenic and nickel are by-products of fossil fuels combustion. Trace amounts of selenium occur naturally in rocks and soils.

Organic EPA priority pollutants found were few. The most commonly occurring one detected was α-BHC (a pesticide). The source of this compound was probably from residential and possibly commercial use within the basins. Bis(2-Ethylhexyl) Phthalate was also detected in two samples. This compound is widely used in plastics such as garden hoses, floor tiles and plastic containers to make them flexible, and their source in samples may have been from contamination from plastic sample ware.

TABLE 9

EPA PRIORITY POLLUTANTS DETECTED IN COMPOSITE SAMPLES OF URBAN RUNOFF[1]

Date Sampled	Monitoring Site	Metals	Pesticides	Volatile Compounds	Other
5/28/81	North Ave.	Copper (Nickel) Lead Selenium Zinc	a- BHC y- BHC	Chloroform	
8/12/81	North Ave.	Arsenic Copper Lead Zinc	a- BHC (y- BHC)		Bis (2-Ethylhexyl)Phthalate Cyanide
5/28/81	Asbury Park	Arsenic Copper Lead (Antimony) Nickel Selenium Zinc	a- BHC		Bis(2-Ethylhexyl)Phthalate
5/28/81	Villa Italia	Arsenic Copper (Nickel) Lead Selenium Zinc	a- BHC		
8/12/81	Villa Italia	Arsenic Chromium Copper Lead Nickel Zinc (Cadimium)	a- BHC	Tetrachlorethylene (Mathylene Chloride)	Cyanide Di-N Butyl Phthalate
5/26/81	Southglenn	Copper Lead (Nickel) Selenium Zinc	a- BHC (y- BHC)	(1,1,1. Trichlorethane)	
8/13/81	Southglenn	Arsenic Copper Lead Selenium Zinc	a- BHC (y- BHC)	1,1,1,-Trichlorethane	(Bis(2-Chloroisoprophyl)Ether)

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[1] Additional pollutants detected in coinciding discrete sample are in parentheses.

Non-priority pollutants found in samples are listed in Table 10. The most significant one detected was 2,4-D (a herbicide) at the Southglenn basin. This herbicide was detected at a concentration at 180 ug/l. No possible source of this pollutant was located, but it was probably from residential use by a homeowner.

As with the regular runoff monitoring effort, both discrete and composite samples of urban ruonff were taken for screening of EPA Priority Pollutants. This sampling effort was independent of the routine runoff monitoring. A single sample (discrete) of "ripe" stormwater from initial runoff and a composite sample representing runoff throughout the storm's duration were collected. It was suspected that higher concentrations of pollutants would be found in the discrete sample, and that a greater number of priority pollutants would be found in the composite samples. Neither trend was found. The lack of additional priority pollutants in composite samples might be due to dilution effects, bringing their concentrations below detection limits.

POLLUTANT LOADING

Pollutant loadings were calculated and compared to meteorological and hydrological variables within the same basin. Loadings were also compared to land use and PEI between basins. It was hypothesized that loadings would vary in a predictable manner depending upon basin characteristics and other variables measured.

The total pounds of pollutants produced from each rainstorm (data from snowstorms were omitted) were calculated at each monitoring basin. These pollutant loads were divided by basin area (in acres) to derive a unit-area loading value, and the resultant figures divided by runoff and rainfall (in inches) to give the following respectively: lbs/acre, lbs/acre/runoff-inch, and lbs/acre/rainfall-inch. Pollutant loads were also divided by rainstorm runoff volume (in cubic feet) and converted to event mean concentrations (EMC) in milligrams per liter (mg/L).

Expression of pollutant loading in these units allows for comparison between storm loads, land use and PEI regardless of basin and storm sites. Event Mean Concentration and lbs/acre/runoff-inch both express pollutant loading in relation to rainstorm runoff and they can be converted to each other if basin area and runoff volume are known.

Average EMCs were not found to be well correlated to basin PEI. There was no smooth continuum of average EMC of a pollutant as a function of PEI. It was thought that effectively impervious surfaces would contribute more load of urban runoff pollutants and that greater average EMCs would

Table 10

NON-PRIORITY POLLUTANTS FOUND IN DRURP SAMPLES[1]

Pollutant	Site Found
6-Methoxy-N,N'-bis(1-methylethyl)-1,3,5-triazine-2,4-dione	Villa Italia
4-Propoxyphenol	Southglenn
Methylheptanol	Villa Italia
3-Methyl-2-cyclohexene-1-one	Villa Italia North Ave. Southglenn
1-(2-Butoxyethoxy) ethanol	Southglenn North Ave.
2,2,4-Trimethyl-1,3-pentanediol	North Ave.
Tributylphosphate	North Ave.
9,10-Anthracenedione or 9,10-Phenanthrenedione	Southglenn
2,4-Dichlorophenoxyacetic acid (2,4-D)	Southglenn
(1,1' biphenyl)-carboxaldehyde	Southglenn
Unidentified substituted alkyl hydrocarbon #1	Villa Italia North Ave. Southglenn
Unidentified substituted alkyl hydrocarbon #2	Villa Italia
Unidentified substituted alkyl hydrocarbon oil	North Ave. Southglenn
Unidentified substituted polycyclic aromatic	Villa Italia
2,/2-(2-Butoxyethoxy) ethoxy/ethanol	Southglenn

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[1] Non-priority pollutants are additional synthetic organic compounds produced by industrial sources.

be found at Villa Italia (PEI = 91.2 percent). Only the EMC of ammonia-nitrogen was consistently greater at this basin. Average EMCs for each basin were plotted against basin PEI for five constituents (Figure 4). These constituents were selected as contributions of them to the South Platte River from urban runoff were found to be significant, at least during wet months (Chapter IV).

Average EMCs were usually the greatest at intermediate basin PEI, and showed substantial variability between basins (Figure 4). They were usually lower at either Rooney Ranch (PEI = 0.6 percent) or Villa Italia (PEI = 91.2 percent). These trends were noted for most of the additional constituents monitored but not depicted.

Regression analysis of average EMC and basin PEI yielded poor relationships. This is due to the large variability in average EMCs between basins. A vague direct relationship between these variables can be noted in the Graphs in Figure 4 except for total suspended solids. EMCs varied too greatly between the limited number of basins monitored to verify this relationship.

Likewise, there was considerable variability between pollutant loading and land use and it was difficult to ascertain distinct loading patterns based on land use. For example, greater loads of nutrients per runoff volume were anticipated from the two single family basins where domestic fertilizer application rates are higher. This was not found. All forms of phosphorus monitored (Table 6), total Kjeldahl nitrogen, and total nitrogen EMCs were greatest on the average from the North Avenue Retention basin (mixed commercial and single family land use). Ammonia-nitrogen was greatest in average EMC at Villa Italia (commercial land use), and nitrite plus nitrate nitrogen EMCs were greatest on the average at North Avenue (mixed land use).

Similarly, higher average EMCs of total metals were expected from the Villa Italia basin. Particularly, greater EMCs of total lead and zinc were anticipated from this basin as Villa Italia is essentially all street surface and these metals are by-products of automobile exhaust and tires, respectively. The greatest EMC for total lead was found at Asbury Park Retention (single family); the EMC of total zinc was greatest on the average at North Avenue (mixed land use). The highest EMCs of total copper and manganese were also from these two basins (Table 7).

Loading of total suspended solids likewise showed no trends in relation to land use. The greatest average EMC was found in the Asbury Park Retention basin (single family) and the lowest in the Cherry Knolls basin (multi-family). Suspended solids loading from Rooney Ranch (natural grassland) was unexpectedly high. Loading of suspended solids was much more variable within and between basins than loading of other constituents. This

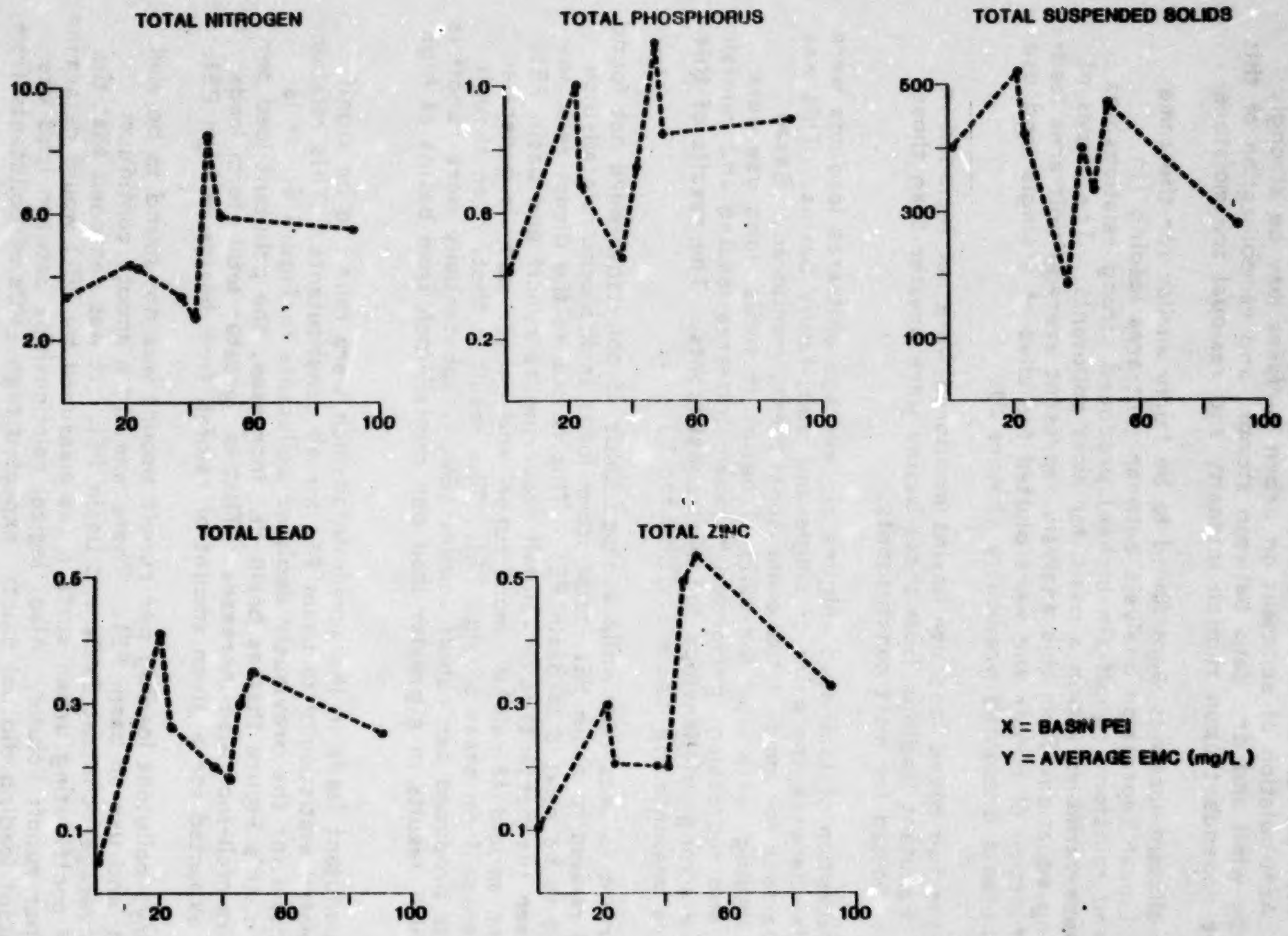

FIGURE 4. AVERAGE EVENT MEAN CONCENTRATIONS (EMCs) AS A FUNCTION OF PEI FOR SELECTED CONSTITUENTS.

may be due to the importance of other factors in determining suspended solids loading such as rainfall intensity, residual soil moisture and antecedent dry days. Accumulation of sediment on urban surfaces may be strongly influenced by wind and dry days between storms. and remobilization of this load may be dependent upon rainfall intensity and residual soil moisture.

Unit-area pollutant-loadings were found to be fairly similar for the same land use. Linear regression analysis between unit-area loading (in lbs/acre) and rainstorm runoff (in inches) produced strong relationships between these variables within a basin for most pollutants. The slopes of the resulting equations from this analysis represent average unit-area loadings as a function of runoff and were plotted for sites of a single land use for the pollutants presented previously (Figure 5).

Data from the two mixed land use basins monitored were not included in Figure 5. Pollutant loadings from these basins were greater than those from basins plotted for most constitutents.

With the exception of total lead (Figure 5), average unit-area loadings were fairly similar between the pairs of single and multi-family basins. This was found to be true for most of the other constituents monitored. Based upon this finding, data from the pairs of basins of similar land use were combined, and regressions performed between unit-area loading and rainfall runoff gave strong relationships for most constituents. The results of this analysis are presented in Table 24 (Chapter V).

It is important to note that while average EMCs of pollutants were not found to be well related to basin PEI, total storm loads in lbs/acre/rainfall-inch were found to be related to basin PEI. This is due to the direct relationship between the percentage of rainfall occurring as runoff and basin PEI. For a given amount of rainfall, more runoff and hence, load, is generated on the average from areas of high PEI. The result is that, even though less load is produced per runoff amount (EMC), substantially more runoff is formed which results in a greater load per rainfall-inch from basins of high PEI.

Average pollutant loads in lbs/acre/rainfall-inch were found to be significantly related statistically to basin PEI for all constitutents. This relationship is shown for the previously depicted pollutants in Figure 6. It is apparent in this Figure that as basin PEI increases, the pollutant load per acre and rainfall-inch also increases. That is, greater total storm loads would be expected for a given amount of rainfall from basins of high PEI.

In summary, pollutant loading per runoff amount was not found to be well related to land use or basin PEI. There was not a smooth continuum between average pollutant EMCs and basin PEI. It was reasoned that the amount of contributing urban surface (as measured by PEI) would determine the load per runoff volume. Also, logical relationships between land use and pollutant loading did not exist: expected high EMCs of pollutants from

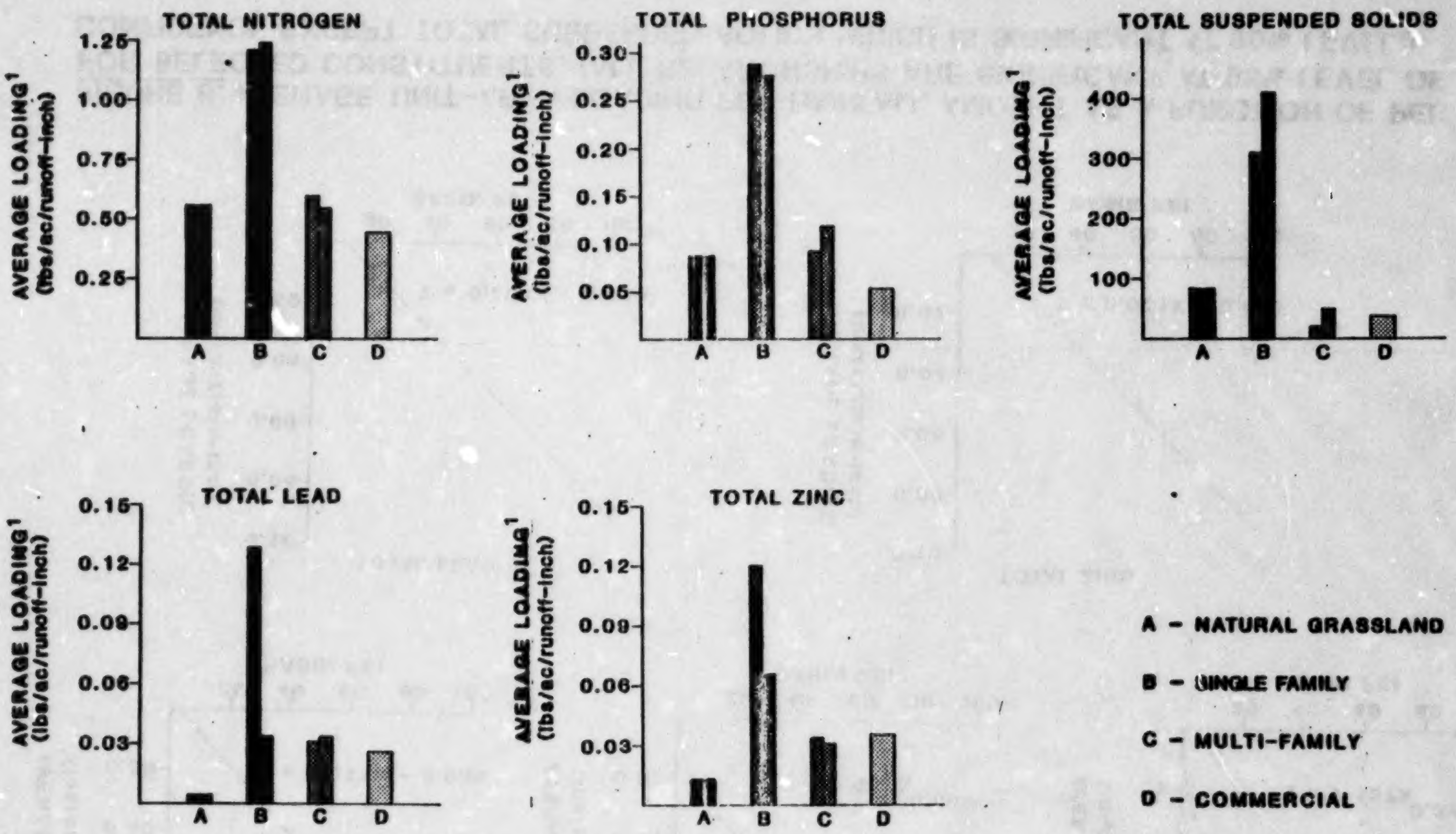

FIGURE 5. COMPARISON OF AVERAGE UNIT-AREA LOADINGS AS A FUNCTION OF RUNOFF FOR URBAN BASINS OF A SINGLE LAND USE FOR SELECTED CONSTITUENTS.

[1] SLOPE OF LINEAR REGRESSION EQUATION BETWEEN lbs/acre CONSTITUENT AND INCHES RUNOFF.

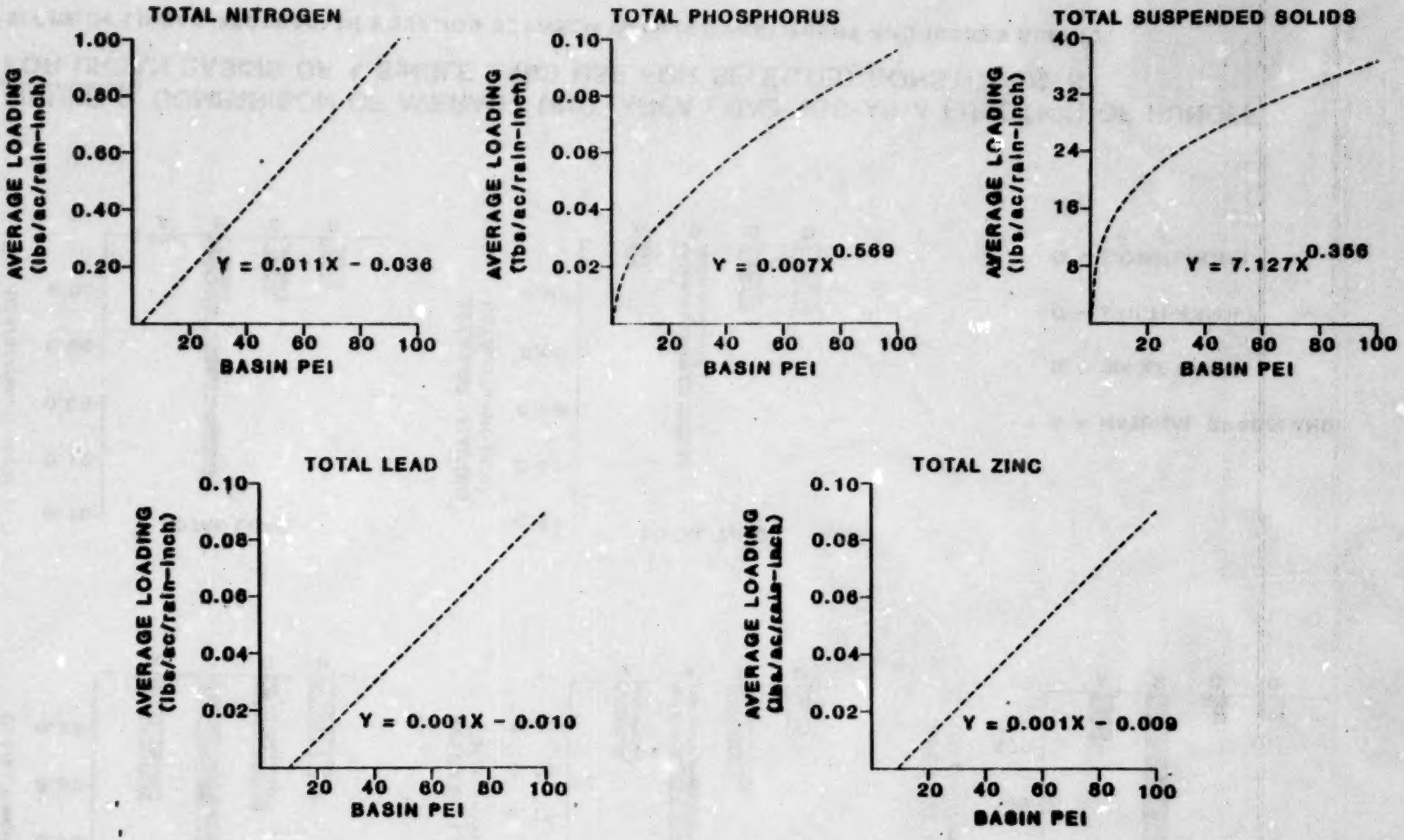

FIGURE 6. AVERAGE UNIT-AREA LOADING PER RAINFALL AMOUNT AS A FUNCTION OF PEI FOR SELECTED CONSTITUENTS. (ALL RELATIONSHIPS ARE SIGNIFICANT AT 95% LEVEL OF CONFIDENCE EXCEPT TOTAL SUSPENDED SOLIDS WHICH IS SIGNIFICANT AT 90% LEVEL.)

specific land uses were not found. Possibly, other basin characteristics and variables (e.g., curb and gutter length, roof area and slope, basin slope, antecedent dry days, and rainfall intensity) that were not studied in this analysis might explain the variability in the data.

Pollutant loading in lbs/acre/rainfall-inch was found to be related to basin PEI. This is explainable by the strong correlation found between percent of rainfall occurring as runoff and basin PEI. Greater amounts of runoff and total storm loads were produced for a given amount of rainfall from basins of high PEI.

Results of this analysis were used to develop desk top planning tools in Chapter V. These tools can be used by local planners and others concerned with impacts of already-existing or proposed alterations in land use on surface water quality. A more detailed analysis of the urban runoff monitoring study and planning tool development is contained in a technical memorandum available through DRCOG.

EFFECT OF DETENTION ON POLLUTANT LOADING

Stormwater detention was evaluated as a Best Management Practice (BMP) for curtailing water quality problems caused by urban runoff. A pervious detention basin was constructed at the North Avenue Retention site during the first sampling season. Rainfall, runoff and water quality measurements were taken approximately 100 yards above the detention basin at North Avenue and immediately below the basin outlet. Eight rainstorms were sampled in total, seven had synoptic data from both sites.

The detention basin decreased loads of most constituents. Reductions in event mean concentration were found for most contaminants after installation of the detention structure.

Average percent reductions in EMC are presented in Table 11. Event mean concentrations were reduced from 1.8 percent for nitrite-plus-nitrate nitrogen to 37.9 percent for manganese. Ortho-phosphate, dissolved organic carbon and total Kjeldahl nitrogen average event mean concentrations increased with detention effects. Increases in dissolved organic carbon can be explained by the presence of organic material within the detention basin. However, total organic carbon was reduced on the average through detention (Table 11).

On the average, 24.4 percent fewer cubic feet of water were measured for a storm at the North Avenue Retention site (calculated from coincident data between sites). Thirty-seven percent more runoff was measured per rainfall-inch on the average at the North Avenue site for rainstorms without the detention structure in place. Reductions in measured storm volume between the sites was probably due to some water retention in the detention basin, possible errors in flow measurements between the two gaging stations, and water losses through soil saturation and exfiltration through channel and basin bottoms.

Table 11

MEAN PERCENTAGE REDUCTIONS IN CONSTITUENT EVENT MEAN CONCENTRATION BY DETENTION[1]

	Event Mean Concentration (mg/L)	
Constituent	**Reduction**	**% Reduction**
Total phosphorus	0.08	8.59
Dissolved phosphorus	0.05	19.0
Ortho-phosphate	+0.02	+12.25
Total Organic Carbon	6.76	8.14
Dissolved Organic Carbon	+9.01	+20.0
Total Suspended Solids	13.9	2.78
Total Lead	0.04	13.6
Total Zinc	0.15	28.9
Total Copper	0.002	23.9
Total Manganese	0.22	37.9
Total Nitrogen	0.74	8.91
Total Kjeldahl Nitrogen	+1.84	+48.8
Ammonia (dissolved)	0.47	23.7
Nitrite-Nitrate Nitrogen	0.04	1.78
Chemical Oxygen Demand	81.1	19.3

[1] "plus" (+) sign indicates mean percentage increase with detention.

For the reductions in event mean concentrations to have occurred, loads had to be decreased per runoff volume. A decrease in runoff volume alone will not decrease the EMC. Processes potentially responsible for this include biological and chemical interactions along with the physical process of sedimentation within the detention basin. Another explanation for the reduced EMCs found is that it is primarily the initial, highly concentrated urban runoff that is filling the basin and being retained and allowed to infiltrate. This would cause a decrease in the total storm load and lower the EMC.

It was hoped that the results of this section would enable a development of some guidelines for detention basin evaluation and construction in the region. Unfortunately due to the narrow range of storms measured, few detention structures monitored, limited outlet structures evaluated and other factors not considered this was not possible. It was concluded that the pervious detention basin studied did reduce loads of most constituents measured. It was most effective in reducing loads of metals, chemical oxygen demand, ammonia, and dissolved phosporus (Table 11). Reductions in loads of total suspended solids were low on the average.

While the limited results of this study suggest that pervious detention basins may be a valuable "Best Management Practice" for curtailing urban runoff pollution in the DRURP study area, more detailed studies on detention basins are needed.

IV. EFFECT OF URBAN RUNOFF ON RECEIVING WATERS

Storm-water runoff generated within the Denver metropolitan area can adversely impact the quality of water of the South Platte River and its tributaries. This is a result of the loads of sediment, nutrients, bacteria and trace elements which accumulate on the land surface and are intermittently flushed into the river as a result of snowmelt and rainstorm runoff. In the Denver region, significant amounts of sediment, fecal coliform bacteria, nutrients, organic matter, and heavy metals enter the river during storm events when compared to discharges from wastewater treatment plants over the same time period.

The South Platte River is the ultimate receiving water for secondary-treated effluents, industrial discharges and urban runoff generated within the Denver metropolitan area. An extensive sanitary-sewer system collects sewage from the basin area and discharges treated effluent at specific points on the river. A network of rooftops, paved areas, gutters, and storm sewers connect to the larger tributary streams which drain storm runoff into the river. Both of these sources of pollution, point and nonpoint, should be considered in assessing the effect of pollutant loading on the river. Stream standards for specific water-quality variables can be used as guidelines to assess if and when adverse effects have occurred in the river. Information from such an assessment can assist policy makers in decisions on levels of treatment and control required to protect desired beneficial uses of the South Platte River.

PURPOSE AND SCOPE

The purpose of this investigation of the South Platte River in Denver was to: (1) characterize water-quality concentrations during ambient streamflow and storm-runoff periods; (2) compare the relative constituent loading from wastewater effluent, urban runoff and dry-weather baseflow; (3) characterize bottom-sediment concentrations of selected chemical constituents during low-flow periods; (4) compare water quality during storm runoff and ambient streamflow periods to established stream standards; and, (5) conduct a survey of stream organisms. This information was developed in order to discuss the effects of urban runoff on beneficial uses of the river.

The time period of monitoring was limited to an 18-month period between April 1980 and September 1981. Through a coordinated effort with the U.S. Geological Survey, five additional tributaries of the South Platte were monitored during three storms. Additional aspects which were considered in the study design but not included in the work plan were definition of time-of-travel for different flow regimes and quantification of the ecological impacts of urban runoff on stream organisms.

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WATER-QUALITY ANALYSIS

A water-quality sampling program was designed to monitor streamflow and water quality of the South Platte River during storm runoff and ambient streamflow conditions. Basin boundaries and the locations of South Platte River and tributary monitoring stations appear on Figure 1. Basin areas and land use distribution within each subbasin have been previously presented in Table 1.

Depth- and width-integrated water samples were collected by DRCOG staff weekly and more frequently during storms at the instream stations. These samples were analyzed by the Metropolitan Denver Sewage Disposal District laboratory. Chemical constituents which were monitored during the 18-month period included those identified in Table 12.

Table 12

WATER-QUALITY VARIABLES MONITORED IN THE SOUTH PLATTE RIVER

Total Suspended Solids
Total Organic Carbon
Total Nitrogen as N[1]
Total Kjeldahl Nitrogen as N
Total Ammonia as N
Nitrite plus Nitrate as N[2]
Nitrite as N
Total Phosphorus as P
Orthophosphate as P
Biochemical Oxygen Demand[3]
Chemical Oxygen Demand
Fecal Coliform Bacteria
Total Dissolved Solids[4]
Total Hardness (as $CaCO_3$)[4]

Sodium
Chloride
Cadmium, Total
Cadmium, Dissolved
Copper, Total
Copper, Dissolved
Iron, Total
Iron, Dissolved
Manganese, Total
Manganese, Dissolved
Lead, Total
Lead, Dissolved
Zinc, Total
Zinc, Dissolved

[1] Calculated as Total Kjeldahl Nitrogen plus Nitrate plus Nitrite.
[2] Nitrate calculated as Nitrate plus Nitrite as N minus Nitrite as N.
[3] 5-day Carbonaceous Biochemical Oxygen Demand (nitrogen-inhibited).
[4] Monitored only during 1981.

In addition, measurements of pH, dissolved oxygen, water temperature and specific conductance were made in the field. Hydrologic data on water-quality constituent concentrations, rainfall and streamflow collected in the monitoring program have been reported by Gibbs and Doerfer (1982).[6]

The analytical determinations were performed under strict quality control provisions and were consistent with approved EPA methods.[7] The total metals procedure (EPA method 4.1.3) was used for both raw and filtered samples in this program. This method is to be distinguished from the total recoverable metals procedure (EPA method 4.1.4) in that a more vigorous digestion is involved in the total metals procedure. Stream standards are based upon total recoverable metal concentrations; whereas, effluent discharge permits are based on the total metal concentration.

The water-quality constituents selected for monitoring were of interest for two reasons. First, stream standards exist for concentrations of dissolved oxygen, pH, fecal coliform bacteria, un-ionized ammonia, nitrite, nitrate, chloride, and most of the metals which were monitored. Secondly, sediment, organic matter, nutrients and potentially toxic heavy metals are of interest due to their effects on river systems and aquatic life.

Comparison of Ambient and Storm Runoff Mean Concentrations

Ambient streamflows were calculated from observations of stream stage made at the time of sampling. Streamflow was calculated by using appropriate corrections to the stream stage and stage/discharge relationships. Records of storm hydrographs were used to develop instantaneous flows at 15-minute intervals. Flow rates were integrated and summed over the storm-runoff period to produce the total flow for the period. Baseflow volume was subtracted from the total flow to arrive at the storm volume.

Storm-runoff loads were calculated by multiplying the constituent concentration times streamflow and a units conversion constant, resulting in instantaneous loading in pounds per second. Concentration values between samples were interpolated and multiplied times the average flow in each 15-minute interval. Loading rates for each interval of the storm period were integrated and summed, producing the total load during the storm. Baseloads for this period were subtracted from the total load to produce the storm-runoff load for each constituent.

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[6] Johnnie W. Gibbs and John T. Doerfer, "Hydrologic Data for Urban Storm Runoff in the Denver Metropolitan Area, Colorado" U.S. Geological Survey Open File Report 82-872, September 1982.

[7] U.S. Environmental Protection Agency, "Methods for the Chemical Analysis of Water and Wastes," Government Printing Office, Washington, D.C., EPA 600/4-079-020, 1979.

Event mean concentrations (EMCs) for each storm were calculated by dividing the total storm-period load by the total streamflow volume. Storm runoff volumes and the mean value of the EMCs for selected constituents from nine storm events monitored between April 1980 and September 1981 are presented in Table 13. The 50th Avenue station was chosen for discussion as it represented cumulative effects of the entire study area.

Ambient water-quality characteristics were calculated for comparison with storm-runoff EMCs. Results for the 78 samples collected at the South Platte River at 50th Avenue station during the monitoring period are presented in Table 14.

Several constituents had mean concentrations greater during storm runoff than during ambient periods. Total suspended solids and fecal coliform bacteria exhibited much greater concentrations during storm events. Total organic carbon, biochemical oxygen demand and chemical oxygen demand concentrations were two to three times greater during storm runoff than ambient conditions. Of the metals, total and dissolved iron, total copper, total manganese, total lead, total zinc and dissolved cadmium produced greater EMCs during storms than ambient streamflow. During low flow conditions, however, dissolved iron and cadmium sometimes had higher maximum concentrations than during storms.

Four constituents had about equivalent mean concentrations in urban runoff and ambient streamflow. These were total nitrogen, total phosphorus, total cadmium and dissolved lead. The higher flow volumes during runoff, however, produced large loads of these constituents during these periods when compared to low flow conditions.

Many of the dissolved constituents had lower EMCs during storms than during ambient streamflow. The nutrients, which occur primarily in the dissolved form, included total ammonia, nitrite, nitrate and orthophosphate. Dissolved forms of copper, manganese and zinc were found to have lower mean concentrations during storms than during ambient streamflow. Total hardness was depressed during storms compared to ambient conditions. Chloride was also apparent in lower concentrations during storms than during ambient streamflow, except during the March 3-6, 1981 snowmelt event which may indicate the effect of street deicing activities.

The lower mean concentrations during storms may be explained by the effect of dilution. The increased amounts of water produced by runoff serve to dilute concentrations in the river, especially the dissolved constituents, under these conditions. However, increased concentrations were observed to occur initially during storm events. The constituents which are in the suspended or particulate phase exhibit the opposite effect. Suspended solids and materials associated with sediment produce greater concentrations in runoff and much greater loads when compared to ambient conditions, especially during low flow periods. This suggests these constituents are primarily associated with land surface sources within the drainage basin.

Table 13

STORM RUNOFF
EVENT MEAN CONCENTRATIONS MONITORED BETWEEN APRIL 1980 AND SEPTEMBER 1981 AT THE SOUTH PLATTE RIVER AT 50TH AVENUE

Water-Quality Variable	Units.	Minimum	Maximum	Mean	Standard Deviation
Storm Runoff Volume	$(10^6 ft^3)$	10.2	94.3	43.1	25.4
Temperature	(°C)	13.0	19.6	16.7	2.5
pH	(S.U.)	7.2	8.1	7.8	0.3
Dissolved Oxygen	(mg/L)	6.4	7.8	7.1	1.0
Total Suspended Solids	(mg/L)	152	1,430	615	345
Total Organic Carbon	(mg/L)	10	52	32	12
Total Nitrogen as N	(mg/L)	2	8	6	2
Total Ammonia as N	(mg/L)	0.27	3.3	1.4	0.90
Un-ionized Ammonia as N[1]	(mg/L)	0.003	0.07	0.03	0.02
Nitrite as N	(mg/L)	0.078	0.19	0.11	0.037
Nitrate as N	(mg/L)	0.82	2.6	1.2	0.54
Total Phosphorus as P	(mg/L)	0.51	2.0	1.4	0.45
Orthophosphate as P	(mg/L)	0.22	0.67	0.40	0.15
Biochemical Oxygen Demand	(mg/L)	3.7	19	13	5.1
Chemical Oxygen Demand	(mg/L)	31	180	99	47
Fecal Coliform Bacteria[2]	(#/100mL)	3,600	7,600	5,300	1,500
Total Hardness (as $CaCO_3$)	(mg/L)	140	200	170	25
Chloride	(mg/L)	33	110	45	26
Cadmium, Total	(µg/L)	1.0	6.3	3.0	2.0
Cadmium, Dissolved	(µg/L)	0.5	4.5	1.6	1.5
Copper, Total	(µg/L)	28	99	63	25
Copper, Dissolved	(µg/L)	5.0	24	6.6	3.0
Iron, Total	(µg/L)	2,800	27,000	11,000	8,200
Iron, Dissolved	(µg/L)	29	130	65	36
Manganese, Total	(µg/L)	160	990	550	280
Manganese, Dissolved	(µg/L)	44	190	110	52
Lead, Total	(µg/L)	59	280	160	78
Lead, Dissolved	(µg/L)	5.0	13	8.5	3.4
Zinc, Total	(µg/L)	94	480	280	130
Zinc, Dissolved	(µg/L)	22	51	38	10

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[1] Un-ionized ammonia calculated from total ammonia concentration and pH and temperature conditions at the time of sampling.

[2] Concentration at peak flow reported; only 4 of 9 storms had sufficient data available for reporting.

Table 14

AMBIENT STREAMFLOW
CONCENTRATIONS MONITORED
BETWEEN APRIL 1980 AND SEPTEMBER 1981
AT THE SOUTH PLATTE RIVER AT 50TH AVENUE

Water-Quality Variable	Units	Minimum	Maximum	Mean	Standard Deviation
Discharge	(ft^3/sec)	42.2	3,280	487	790
Temperature	(°C)	0.0	28	14	6
pH	(S.U.)	7.3	8.7	8.0	0.3
Dissolved Oxygen	(mg/L)	5.2	12.4	8.6	1.6
Total Suspended Solids	(mg/L)	5.0	775	79	115
Total Organic Carbon	(mg/L)	3.0	66	13	11
Total Nitrogen as N	(mg/L)	0.4	11	5	3
Total Ammonia as N	(mg/L)	0.01	6.2	2.3	1.7
Un-ionized Ammonia as N[1]	(mg/L)	0.003	0.03	0.08	0.08
Nitrite as N	(mg/L)	0.02	0.6	0.2	0.1
Nitrate as N	(mg/L)	0.25	3.1	1.7	0.7
Total Phosphorus as P	(mg/L)	0.10	2.6	1.1	0.6
Orthophosphate as P	(mg/L)	0.01	2.4	0.8	0.5
Biochemical Oxygen Demand	(mg/L)	1	26	7	4
Chemical Oxygen Demand	(mg/L)	12	116	29	15
Fecal Coliform Bacteria[2]	(#/100mL)	10	58,000	1,100	9,700
Total Hardness (as $CaCO_3$)	(mg/L)	187	324	256	40
Chloride	(mg/L)	16	324	63	39
Cadmium, Total	(µg/L)	0.5	21	3	3.0
Cadmium, Dissolved	(µg/L)	0.0	14	1	2
Copper, Total	(µg/L)	5.0	120	29	22
Copper, Dissolved	(µg/L)	0.0	30	10	6.6
Iron, Total	(µg/L)	240	12,000	1,800	2,100
Iron, Dissolved	(µg/L)	5.0	330	37	58
Manganese, Total	(µg/L)	40	440	240	81
Manganese, Dissolved	(µg/L)	10	360	170	97
Lead, Total	(µg/L)	5.0	200	30	29
Lead, Dissolved	(µg/L)	0.0	30	9.7	5.6
Zinc, Total	(µg/L)	40	440	110	61
Zinc, Dissolved	(µg/L)	5.0	150	47	27

[1] Un-ionized ammonia calculated from total ammonia concentration and pH and temperature conditions at the time of sampling.
[2] Geometric mean and arithmetic standard deviation reported.

Comparison of Point Source, Baseflow, and Storm Runoff Loads

The primary purpose of the instream monitoring program was to assess the effects of urban runoff on the South Platte River in the Denver metropolitan area. However, in order to accomplish this objective, a quantification of loads from other sources contributing contaminants to the river was necessary. These additional sources include the baseload entering from the upstream boundary of the basin, point-source contributions from municipal wastewater treatment plants and industrial discharges, and dry-weather baseflow originating as groundwater and irrigation return flows within the basin. A secondary source of loading is the resuspension of previously deposited sediments from all of the primary sources identified above. By accounting for all of these input-source loads, the relative contribution from storm runoff could be determined.

For the purposes of this discussion, six constituents were selected for reporting. These were total suspended solids, total organic carbon, total nitrogen, total phosphorus, total lead and total zinc. These constituents were chosen as they represent water-quality characteristics of suspended sediment, organic matter, nutrients, and potentially toxic trace metals. In general, these constituents are of interest, particularly with respect to their effects on river systems and aquatic life.

Estimation of Point Source Loads

Point-source loads for the study area were estimated for the 18-month study period. Three municipal wastewater treatment plants (WWTPs) discharge effluent directly to streams within the study area basin. Industrial discharges, primarily from Public Service Company of Colorado power plants and the Gates Rubber Company were evaluated and determined to not be significant; and thus, these were not included in the point source loads.

The Littleton/Englewood and Lakewood WWTPs discharge into the South Platte River and the Glendale WWTP discharges to Cherry Creek. Figure 7 delineates the service areas for these three treatment plants in the study area. The Littleton/Englewood treatment plant is situated in the southern part of the study area and discharged an average of 15.7 million gallons per day (MGD) during the study period. The Lakewood treatment plant is located in the western part of the study area and discharged an average of 1.8 MGD. Effluent from the Lakewood plant was piped about two miles to the river to the discharge point which is located immediately upstream of Lakewood Gulch on the South Platte River. The Glendale treatment plant discharged an average of 1.0 MGD to Cherry Creek at a point about 5.5 miles above the confluence with the South Platte River.

Effluent from the lower part of the study area is discharged downstream of the 50th Avenue monitoring station. Point source loads originating from the lower part of the basin area were included in the analysis as if secondary treated effluents were discharged at the 50th Avenue monitoring location.

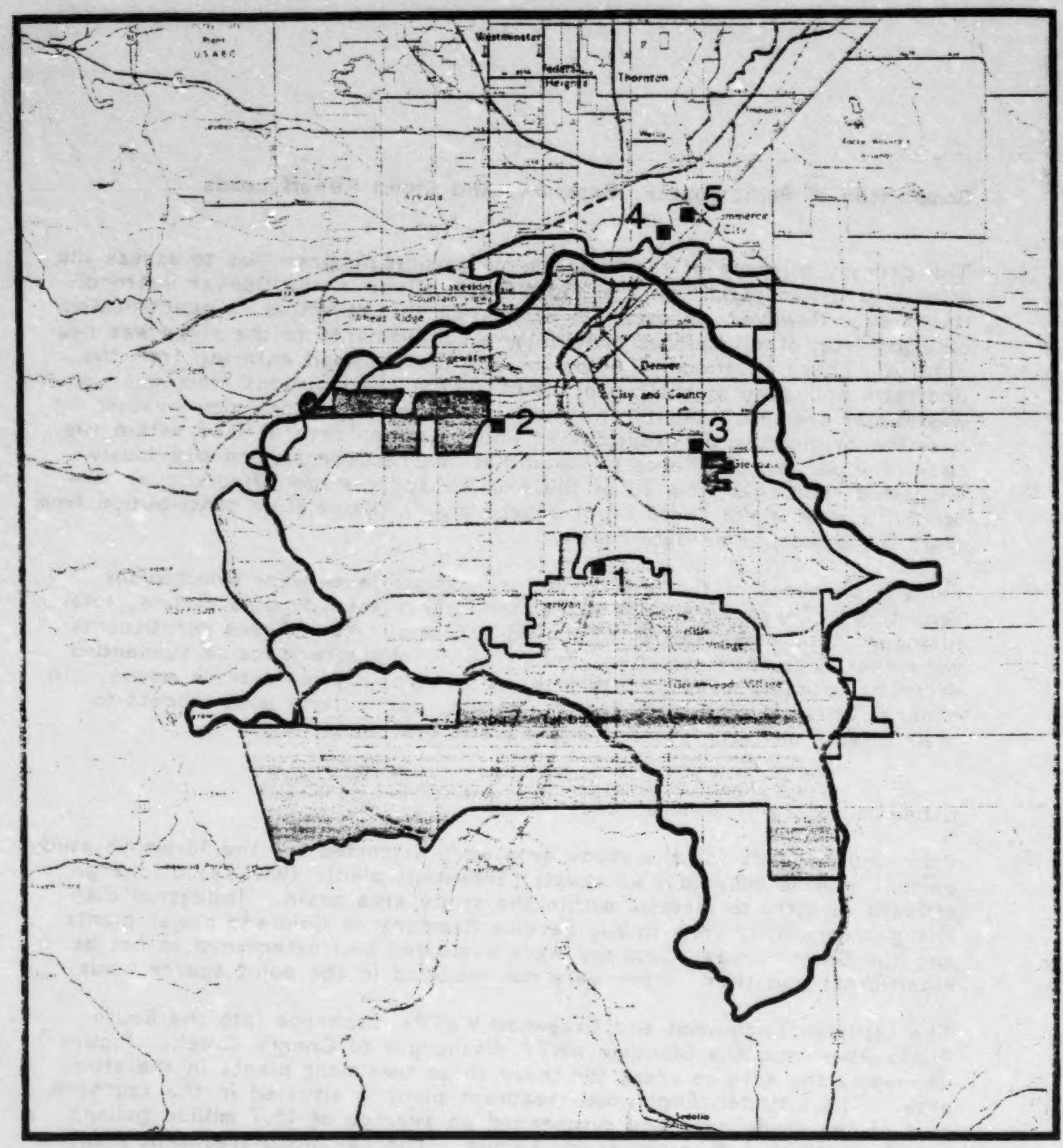
Westminster
Federal Heights
Thornton
Arvada
Commerce City
Lakeside
Mountain View
Wheat Ridge
Edgewater
Denver
City and County
Glendale
Greenwood Village
Sedalia
1
2
3
4
5

FIGURE 7. MAP OF THE STUDY AREA SHOWING BASIN BOUNDARY, LOCATIONS OF WASTEWATER TREATMENT PLANTS AND TREATMENT PLANT SERVICE AREAS.

-WASTEWATER TREATMENT PLANTS AND SERVICE AREAS

~ BASIN BOUNDARY

■1 LITTLETON/ENGLEWOOD ▬

■2 LAKEWOOD ▬

■3 GLENDALE ▬

■4 DENVER NORTHSIDE ▨

■5 METRO ▨

Even though a discharge point does not actually exist at this location on the river, a procedure was developed to accurately estimate the point source effluent load originating from the lower part of the basin.

The service area of the Denver Northside plant has also been delineated on Figure 7. The Denver Northside treatment plant is located immediately downstream of the South Platte River at 50th Avenue monitoring station. Primary-treated effluent was piped two miles downstream from here to the Metropolitan Denver Sewage Disposal District plant for secondary treatment. An average influent flow of 74 MGD was received at the Metro plant from the Denver Northside plant during the April 1980 through September 1981 period. This amount corresponds to about 55 percent of the total 135 MGD processed at the Metro plant. The surface-runoff drainage-basin area defined by the 50th Avenue monitoring station corresponds closely with the four wastewater treatment plant service areas (See Figure 7).

Wastewater effluent concentrations were based on data obtained from the treatment plants from National Pollution Discharge Elimination System (NPDES) self-monitoring data. To the extent these data were available, monthly concentration values for total suspended solids, total organic carbon, total nitrogen, total phosphorus, total lead and total zinc were multiplied by mean monthly discharge volumes and an appropriate conversion factor to derive monthly loads for the April 1980 through September 1981 period. Missing values were estimated for the Lakewood and Glendale discharges from concentration values supplied by the Littleton/Englewood treatment plant when necessary. Flow-weighted concentrations from the Littleton/Englewood NPDES data were applied to reported monthly flow volumes from Lakewood and Glendale to estimate monthly loads. These loads were added to the Littleton/Englewood WWTP loads to calculate the point source effluent loads originating from the upper part of the study area basin.

The volume of influent sewage from the Denver Northside plant primary effluent was measured separately as it entered the Metro plant for secondary treatment. This allowed calculations of the lower basin point source loads to be made. Concentrations of wastewater effluent from monthly NPDES data available from Metro were applied to Denver Northside flow volumes to calculate mean monthly point source effluent loads from this lower part of the basin area. The sum of upper basin and lower basin effluent loads represent the total point source loads of secondary-treated effluent generated within the basin area defined by the 50th Avenue monitoring station.

Estimation of Baseflow Loads

Two components of the baseflow at 50th Avenue were identified and have been separated. The first component of baseflow is the amount of water entering the 50th Avenue basin at its upstream boundaries. The upper basin boundary on the South Platte River is located at the Littleton gaging station (See Figure 1). Two flood control dams define boundaries on the eastern and western sides of the basin, Cherry Creek and Bear Creek dams, respectively. No releases of water occurred from Cherry Creek dam during the study period. Records of Bear Creek streamflows and diversions were obtained from the water commissioner to estimate the amounts of water entering the basin from Bear Creek. The summation of Littleton and Bear Creek streamflows constituted the total upstream baseflow.

The second component of baseflow at 50th Avenue is the amount of water generated within the drainage basin itself. Although a certain amount of this baseflow is groundwater, a more significant amount is return flow from urban lawn watering during dry weather. This water enters the river from numerous storm sewers and tributary streams in the basin. Because groundwater could not be separated from the dry-weather urban runoff, this component is collectively termed dry-weather baseflow. The amount of dry-weather baseflow was calculated by subtracting the upstream baseflow from the amount of baseflow observed at the mouth of the basin at 50th Avenue. The baseflow at 50th Avenue was first calculated by subtracting the upper basin effluent volumes and storm-runoff volumes from records of streamflow hydrographs at the gaging station at 50th Avenue.

Baseflow loads at 50th Avenue were calculated based on relationships between instantaneous streamflow and constituent concentrations monitored during ambient conditions. Regression equations were developed for each of the selected constituents and are further described in Chapter V. Mean daily discharge during ambient streamflow and estimated baseflow values during storm-runoff periods were used to predict daily loads at 50th Avenue. These values were summed into monthly values and the upper basin effluent loads occurring during each month were subtracted to estimate total monthly baseflow loads at 50th Avenue. Separate equations were developed for the upstream component of baseflow, and streamflow volumes were similarly used to estimate the upstream component of the baseflow load. It is important to note the distinction between the baseflow loads entering the basin at the upstream boundary and the total baseflow loads calculated at the 50th Avenue station. In order to denote the additional amount of loading from the basin during dry-weather baseflow, the upstream component was subtracted from the 50th Avenue baseflow load. This amount was assumed to constitute the dry-weather baseflow load for each constituent arising from the study area basin.

Estimation of Storm Runoff Loads

Storm-runoff loads for total suspended solids, total organic carbon, total nitrogen, total phosphorus, total lead and total zinc were estimated for all storms occurring during the 18-month period. This was accomplished by deriving relationships between monitored storm loads and storm volumes. The equations resulting from regression analysis are presented and discussed further in Chapter V.

On days when storm events occurred, baseflows were estimated by visually inspecting strip-chart records of streamflow at 50th Avenue. Rainfall records assisted in interpretation of days influenced by storm runoff, and previous-day discharge assisted in estimating baseflow values. This method of separating runoff from baseflow was used to estimate storm-runoff volume for unmonitored events. Comparisons with monitored storm volumes indicated these estimates were accurate to within about plus-or-minus five percent of the monitored storm volumes.

The regression equations developed which estimate storm loads based on storm volume (Chapter V) were used to estimate storm loads for both monitored and unmonitored storms. Loads were predicted using the equations for both monitored and unmonitored storms to yield statistically acceptable results. Estimated storm loads for individual events occurring during April 1980 through September 1981 were calculated and summed into monthly storm loads for each of the selected constituents.

Results and Discussion

Total loading estimated to have occurred within the South Platte River basin at 50th Avenue during the three 6-month periods between April 1980 and September 1981 were calculated and are presented in Table 15. These values can be interpreted as being those loads produced within the study area basin from storm runoff and secondary-treated effluents added to the amount of baseflow load occurring in the river from upstream sources and dry-weather baseflow. The total loads which actually occurred in the river at the 50th Avenue station are those exclusive of lower basin effluent loads. Even though the lower basin effluent loads were not actually discharged at or above the 50th Avenue monitoring station, these loads were generated within the study area and an interpretation of relative loading from urban runoff, baseflow, and secondary-treated effluents can be made based on total basin area. The percentage contribution each component load comprised of the total basin load was calculated and are presented in Table 16.

The point source loads from both the upper and lower parts of the 50th Avenue basin were relatively constant when compared between the three 6-month time periods (Table 15). The lower part of the basin contributed about four times the amount of flow, suspended solids, organic carbon, nitrogen and phosphorus than the wastewater effluent from the upper part of the basin area. These greater amounts of solids, organic matter and nutrients were due primarily to the increased ratio of flow volumes between areas. The lower part of the basin contributed about three times the amount of lead and ten times the amount of zinc when compared to the upper basin sources. The relatively larger amounts of metals may have been due to the more industrial nature of influent received at the lower basin wastewater service area.

The point sources contributed the greatest amount of nitrogen, phosphorus, and organic carbon produced within the 50th Avenue basin (Table 15). During the 1981 water year (between October 1980 and September 1981), the upper and lower basin point sources combined contributed about 50 percent of the total volume of streamflow at 50th Avenue. In other words, the wastewater effluent doubled the flow of the river. During this period,

Table 15

ESTIMATED POINT SOURCE, BASEFLOW, AND STORM RUNOFF LOADS FOR APRIL 1980 THROUGH SEPTEMBER 1981 FOR THE SOUTH PLATTE RIVER AT 50TH AVENUE

(volume in cubic feet, load in pounds)

	Total Volume $(x10^6)$	Total Suspended Solids $(x10^6)$	Total Organic Carbon $(x10^5)$	Total Nitrogen $(x10^4)$	Total Phosphorus $(x10^4)$	Total Lead $(x10^3)$	Total Zinc $(x10^3)$
April 80-September 80							
Upstream Baseflow[1]	15,939	150.7	33.0	8.3	8.7	17.2	48.9
Upper Basin Effluent[2]	513	0.9	7.6	57.0	12.5	1.2	2.0
Lower Basin Effluent[3]	2,221	3.3	33.2	291.0	54.4	1.7	10.8
Dry-Weather Baseflow[4]	615	121.4	65.5	106.3	15.2	27.5	40.5
Stormwater Runoff[5]	814	59.4	28.4	67.0	8.6	10.4	15.9
Period Total	20,102	335.7	167.7	529.6	99.4	58.0	118.1
October 80-March 81							
Upstream Baseflow[1]	901	1.1	0.4	0.8	0.3	0.7	1.8
Upper Basin Effluent[2]	411	0.6	6.9	58.7	14.8	0.6	1.3
Lower Basin Effluent[3]	1,766	2.2	29.7	252.0	63.3	1.7	10.7
Dry-Weather Baseflow[4]	522	1.6	6.9	22.3	1.4	1.6	8.9
Stormwater Runoff[5]	221	6.4	3.8	5.1	1.6	2.7	6.0
Period Total	3,821	11.9	47.7	338.9	81.4	7.3	28.7
April 81-September 81							
Upstream Baseflow[1]	1,692	3.2	0.7	1.3	0.7	1.3	3.6
Upper Basin Effluent[2]	479	0.9	7.0	56.4	14.6	0.4	1.5
Lower Basin Effluent[3]	1,943	1.8	27.1	226.0	56.6	1.2	14.6
Dry-Weather Baseflow[4]	641	2.0	10.6	35.3	3.1	3.6	13.0
Stormwater Runoff[5]	440	24.5	11.8	16.2	4.4	5.7	12.2
Period Total	5,195	32.4	57.2	335.2	79.4	12.2	44.9

[1] Baseflow from upstream sources on South Platte and Bear Creek.
[2] Wastewater from Littleton/Englewood, Lakewood and Glendale plants.
[3] Wastewater from Central Denver Service area of Metro plant.
[4] Baseflow from groundwater and irrigation return flows.
[5] Runoff generated from within study area basin.

Table 16

POINT SOURCE, BASEFLOW, AND STORM RUNOFF LOADS EXPRESSED AS A PERCENTAGE OF TOTAL BASIN LOADS FOR APRIL 1980 THROUGH SEPTEMBER 1981 FOR THE SOUTH PLATTE RIVER AT 50TH AVENUE

(percentages do not necessarily add to 100 due to rounding of values)

	Total Volume (%)	Total Suspended Solids (%)	Total Organic Carbon (%)	Total Nitrogen (%)	Total Phosphorus (%)	Total Lead (%)	Total Zinc (%)
April 80-September 80							
Upstream Baseflow[1]	79.3	44.9	19.7	1.6	8.8	29.7	41.4
Upper Basin Effluent[2]	2.6	0.3	4.5	10.8	12.6	2.1	1.7
Lower Basin Effluent[3]	11.0	1.0	19.8	54.9	54.7	2.9	9.1
Dry-Weather Baseflow[4]	3.0	36.2	39.1	20.1	15.3	47.4	34.3
Stormwater Runoff[5]	4.0	17.7	16.9	12.7	8.7	17.9	13.5
October 80-March 81							
Upstream Baseflow[1]	23.6	9.2	0.8	0.2	0.4	9.6	6.3
Upper Basin Effluent[2]	10.8	5.0	14.5	17.3	18.2	8.2	4.5
Lower Basin Effluent[3]	46.2	18.5	62.3	74.4	77.8	23.3	37.3
Dry-Weather Baseflow[4]	13.7	13.4	14.5	6.6	1.7	21.9	31.0
Stormwater Runoff[5]	5.8	53.8	8.0	1.5	2.0	37.0	20.9
April 81-September 81							
Upstream Baseflow[1]	32.6	9.9	1.2	0.4	0.9	10.7	8.0
Upper Basin Effluent[2]	9.2	2.8	12.2	16.8	18.4	3.3	3.3
Lower Basin Effluent[3]	37.4	5.6	47.4	67.4	71.3	9.8	32.5
Dry-Weather Baseflow[4]	12.3	6.2	18.5	10.5	3.9	29.5	29.0
Stormwater Runoff[5]	8.5	75.6	20.6	4.8	5.5	46.7	27.2

[1] Baseflow from upstream sources on South Platte and Bear Creek.
[2] Wastewater from Littleton/Englewood, Lakewood and Glendale plants.
[3] Wastewater from Central Denver Service area of Metro plant.
[4] Baseflow from groundwater and irrigation return flows.
[5] Runoff generated from within study area basin.

about 90 percent of the total loads for both phosphorus and nitrogen were due to point source loading of the river (Table 16). Similarly, about 70 percent of the total organic carbon load was due to point sources. During the April through September 1980 period, the point sources accounted for only about 14 percent of the flow yet produced about 67 percent of the phosphorus and nitrogen loads, and about 24 percent of the total organic carbon load from all sources (Table 16). The decreased relative percentages in this period compared to the 1981 water year are due to the greater amount of streamflow volume from baseflow entering the basin at the upstream boundaries.

Stormwater runoff loads were significant for total suspended solids and total lead. The relative percentages of volume produced from stormwater were, however, small in comparison with other sources. Data presented in Table 16 indicate that storm runoff was only 9 percent of the volume of water passing through the basin between April and September of 1981, yet contributed about 76 percent of the total suspended solids load. A similar pattern is evident for lead where 47 percent of the total basin load was due to stormwater runoff. In comparison, only about 5 percent of the nitrogen and phosphorus loads were carried by the storm-runoff volume in the basin.

A similar trend is noticed during the winter period between October 1980 and March 1981. Storm runoff, primarily in the form of snowmelt events, accounted for only about 6 percent of the total basin volume, yet contributed 54 percent of the suspended solids and 37 percent of the lead within the basin. The storm-runoff volume during April through September 1980 was double the amount during April through September in 1981 (Table 15). The loads of sediment and lead were also about double; however, when taken as a percentage (Table 16) storm-runoff accounted for only 4 percent of the total volume, and 18 percent of the loads for both suspended solids and lead. During this period there was considerably higher baseflow from upstream sources.

Baseflow loads from upstream sources originate at two locations, from the South Platte and from Bear Creek. There is always a load carried into the basin from the upstream location on the South Platte River at Littleton (See Figure 1). Normally, all of the streamflow in Bear Creek is diverted above Bear Creek Dam except during high streamflow conditions produced by mountain snowmelt in early summer. Because the source of this water is mountain runoff, and the fact that flood control dams allow settling of sediment prior to release into the study area, loads carried by this baseflow into the basin are usually low compared to other sources. The data in Tables 15 and 16 indicate this condition during water year 1981. Loads for organic carbon, phosphorus, nitrogen, lead and zinc are quite low. Suspended solids from the upstream baseflow accounted for only about 10 percent of the total load passing through the 50th Avenue basin from about 28 percent of the total water volume.

A considerable difference is noted, however, during April through September 1980. The total flow during this 6-month period was more than double that for all of water year 1981 (Table 15). Baseflow from upstream sources amounted to about 80 percent of the total flow and produced 45 percent of the suspended solids load. The loads of nutrients and metals were still apparent in similar volume-to-load ratios as in water year 1981, but due to this source being in such high proportion to the total flow, loads of these constituents were much higher than during 1981 (Table 16).

Dry-weather baseflow is generated from within the 50th Avenue basin as either groundwater or irrigation return flow. Loads from these two components could not be separated, but groundwater is not considered to be a major component of streamflow due to the semi-arid climate and extent of imperviousness within the basin. Return flows from sprinkling of urban grassed areas are largely surface returns and not groundwater due to the large amount of evapotranspiration of water applied. When lawns are over-watered, a certain amount of trickleflow occurs which can be considered dry-weather urban runoff. This source of water arises from the basin area, and during this particularly dry period in water year 1981, was nearly equal to or sometimes greater than, the amount of wet-weather urban runoff, as evidenced by volumes listed in Table 15.

The loads of total nitrogen from dry-weather baseflow during water year 1981 were greater than stormwater runoff. Loads of phosphorus were somewhat less, and loads of zinc were slightly larger than storm runoff. Lead and suspended solids were much greater from storm runoff, however, and organic carbon loads were similar between these two sources. Except for nitrogen and phosphorus, dry-weather baseflow loads were equal to or greater than upper basin wastewater effluent loads for suspended solids, organic carbon, lead and zinc during water year 1981.

A different situation is evident, however, when the period April through September 1980 is considered. Dry-weather baseflow volumes during this period are similar to those during the comparable summer period in 1981 but constituent loads are considerably higher. Although not immediately apparent, this condition might be explained as described in the following section.

Effect of Resuspension on Stream Loading

The constituent loads generated by wastewater treatment plants are readily quantifiable because flows and concentrations are easily measured and do not fluctuate widely over short periods of time. Ambient streamflow loads can be accurately measured if streamflow data are good and water quality sampling data define changes in concentrations evident over the time scales these changes happen to occur in the water. Storm runoff loading is difficult to quantify because of the rapidly changing conditions of streamflow and concentrations and the problems inherent in monitoring these changes throughout the storm-runoff periods. Also, physical and chemical processes interact to such an extent that distributing a load measured in the stream back to the basin from which it came is a generalized procedure at best. Channel processes of scour and deposition are important because the contaminants suspended and dissolved in the flow define the chemical characteristics of the water.

The effects of resuspension are probably evident during high streamflow conditions during both storm runoff and mountain-snowmelt periods. The disproportionate amount of loading attributed to dry-weather baseflow during April through September 1980 is probably not due entirely to dry-weather loading but probably includes a component due to resuspension. This can be realized by comparing flow volumes between the summer periods in both 1980 and 1981; volumes were comparable between periods (Table 15). More than likely the loads were also comparable, but due to the method of calculation of dry-weather load as a residual, the component of the total baseflow load not accounted for by the upstream sources was placed into the dry-weather baseflow category. This large baseflow load did occur at 50th Avenue during 1980. As it probably was not from dry-weather runoff, this indicates its source may have been resuspension of channel sediment. Because of the high streamflow produced by mountain snowmelt, and the relatively low loads carried by this amount of water at the basin boundaries, the stream velocity could have acted to resuspend sediment to achieve an equilibrium condition. All of the constituents exhibited this effect, with suspended solids producing the largest increases when compared to 1981 data. Organic matter, nutrients, and metals exist to a large extent in a particulate phase and thus could have been resuspended from the bottom-sediments as well.

Storm-runoff water-quality data collected during a coordinated sampling effort between DRCOG and the U.S. Geological Survey was used to calculate storm runoff loads for a total of six tributaries and three instream stations on the South Platte during one storm. A report has been prepared which discusses the monitoring effort and data collected and includes a discussion of the effect of resuspension as a source of loading.*

Storm-runoff loads for phosphorus and lead were calculated for each of the tributaries and mainstem stations (Figure 1) monitored during the storm of August 14, 1980. These tributary areas accounted for 45 percent of the total basin area at 50th Avenue. Eighteen percent of the total phosphorus load and 42 percent of the total lead load measured at the 50th Avenue station originated from the sum of the monitored tributary areas. Assuming that the load from the remaining 55 percent of the basin area which was not monitored was similar on a unit-area basis, then a substantial part of the load at 50th Avenue may have been resuspended by scour from accumulated sediments in the channel bottom of the South Platte River.

Using this reasoning, it was estimated that 60 percent of the phosphorus load and 7 percent of the lead load could be accounted for as resuspended bottom sediments. This indicates that lead is primarily associated with land-surface sources because only 7 percent was resuspended material. The data for phosphorus, however, indicated that the channel may have been the source of 60 percent of the phosphorus load monitored at the 50th Avenue station during this storm. Resuspension of bottom sediments during both storm runoff and high ambient streamflow conditions should also be considered as a source of loading within the 50th Avenue study area basin.

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* Steven R. Blakely, Martha H. Mustard and John T. Doerfer, "Analysis of the August 14, 1980 Rainstorm and Storm Runoff to the South Platte River in the Southern Denver Metropolitan Area, Colorado," U.S. Geological Survey Water Resources Investigations Report 83-1438, 1983.

BOTTOM-SEDIMENT ANALYSIS

Sediments generated from point and nonpoint sources eventually settle to the river bottom. The disposition of these bottom-sediments in the river is important because they can continue to interact with the water which flows over them long after they have been deposited. Sediments tend to accumulate in certain places along the river and are scoured out in others. During low-flow conditions, velocities are insufficient to maintain discharged sediments in suspension and these will settle out close to their source. Higher flow velocities, which occur during storm runoff and mountain snowmelt periods, can resuspend bottom-sediments and transport them downstream. Physical processes of scour and deposition should be considered as well as the chemical interactions of water and sediment. Because many chemical constituents are associated with sediment particles, particularly trace metals, an investigation of bottom-sediment chemistry in the channel of the South Platte River in Denver was included in the receiving water analysis of the DRURP.

Study Design

A bottom-sediment sampling program of the South Platte River in Denver was designed by DRCOG with the assistance of Woodward-Clyde Consultants.[9] The primary purpose of this program was to collect information on the concentrations of selected metals and nutrients in the sediments in a reach of the South Platte River approximately between Littleton and Brighton, Colorado. Sampling sites were chosen relative to inflows from major tributary streams and discharges from major municipal and industrial point sources. Consideration was given in the selection to locating sampling points just upstream from the next major inflow potentially affecting sediment chemistry. In this manner, the effects of incomplete mixing of sediments in the stream cross section from the source of inflow being monitored were minimized. Multiple subsamples were collected at five points in a cross section from the river channel and composited into a single sample to insure that representative samples were collected.

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[9] Timothy D. Steele and John T. Doerfer, "Bottom-Sediment Chemistry and Water Quality of the South Platte River in the Denver Metropolitan Area Colorado," in Proceedings of the 1983 International Symposium on Urban Hydrology, Hydraulics, and Sediment Control, July 25-28, 1983, University of Kentucky, Lexington, Kentucky.

Chemical constituents which were analyzed are listed in Table 17.

Table 17

BOTTOM-SEDIMENT CONSTITUENTS MONITORED
IN THE SOUTH PLATTE RIVER[1]

Total Phosphorus	Copper	Cadmium
Total Nitrogen	Lead	Iron
Percent Organic Matter	Zinc	Manganese

[1] Metals determined using EDTA chelation-extraction method.

Bottom-sediment samples were sieved into five particle-size fractions and individual analyses were performed by the Soil Testing Laboratory of Colorado State University. The weight of each dry fraction was measured to calculate the percent each fraction was of the total sample. Weighted-mean concentrations were calculated and plotted to show changes in constituent levels along the river profile.

A total of 20 sites along the stream reach of the mainstem South Platte River were selected and sampled on February 24, 1981. These bottom-sediment sampling stations are listed in Table 18 and appear on Figure 8. Sites above the study area and far below the 50th Avenue monitoring station were chosen to assess the chemistry and particle-size distribution of sediments generated within the Denver metropolitan area. Four of the sites coincided with active stream-gaging stations in the program (Figure 1).

Results and Discussion

Figure 9 illustrates the results of bottom-sediment sampling on February 24, 1981 for selected constituents. These constituents were chosen for reporting because of their association to either point or nonpoint sources.

Lead and zinc have been demonstrated to be highly associated with urban runoff, as mentioned in the previous section of this chapter. The stream-reach plot of lead shows changes in the river profile from upstream (left) to downstream (right). A general increase in lead concentrations occurred in the urbanized area of Denver, followed by a gradual decrease in concentrations in a downstream direction. The three peaks at Sites 5,

Table 18

BOTTOM SEDIMENT SAMPLING STATIONS, DENVER METROPOLITAN AREA, SOUTH PLATTE RIVER FEBRUARY 24, 1981 RECONNAISSANCE SURVEY

Station Designation	Location Description	River Mile
1	Near Columbine Valley	330.7
2	At Littleton gaging station (06710000)	328.9
3	Above Big Dry Creek (West Chenango Ave.)	328.1
4	Above Bear Creek (Oxford Avenue Bridge)	326.6
5	Above Little Dry Creek (Evans Avenue Bridge)	325.3
6	Above Harvard Gulch (below PSC-Arapahoe PP and Bi-City WWTP)	323.8
7	Above Sanderson Gulch (Florida Avenue Bridge) At Florida Avenue gaging station (06711590)	322.7
8	Near Alameda Avenue Bridge	320.7
9	Above Weir Gulch (8th Avenue Bridge)	319.0
10	Above Lakewood Gulch (13th Avenue Bridge) (below PSC-Zuni PP)	319.0
11	Near I-25. (Valley Highway Bridge)	318.5
12	Above Cherry Creek (Speer Blvd. Bridge, Confluence Park)	317.7
13	At Denver gaging station (19 St. Bridge) (06714000)	317.2
14	At 38th Street Bridge	315.1
15	At 50th Avenue gaging station (06714130)	314.3
16	Above MDSDD #1 WWTP outfall and Sand Creek	312.1
17	Above Clear Creek (I-76 Bridge)	311.7
18	Near 88th Avenue Bridge (at South Adams County WWTP)	308.7
19	At Henderson gaging station (123rd Avenue Bridge) (06720500)	301.7
20	Near 160th Avenue (Highway 7) Bridge (near Brighton)	295.8

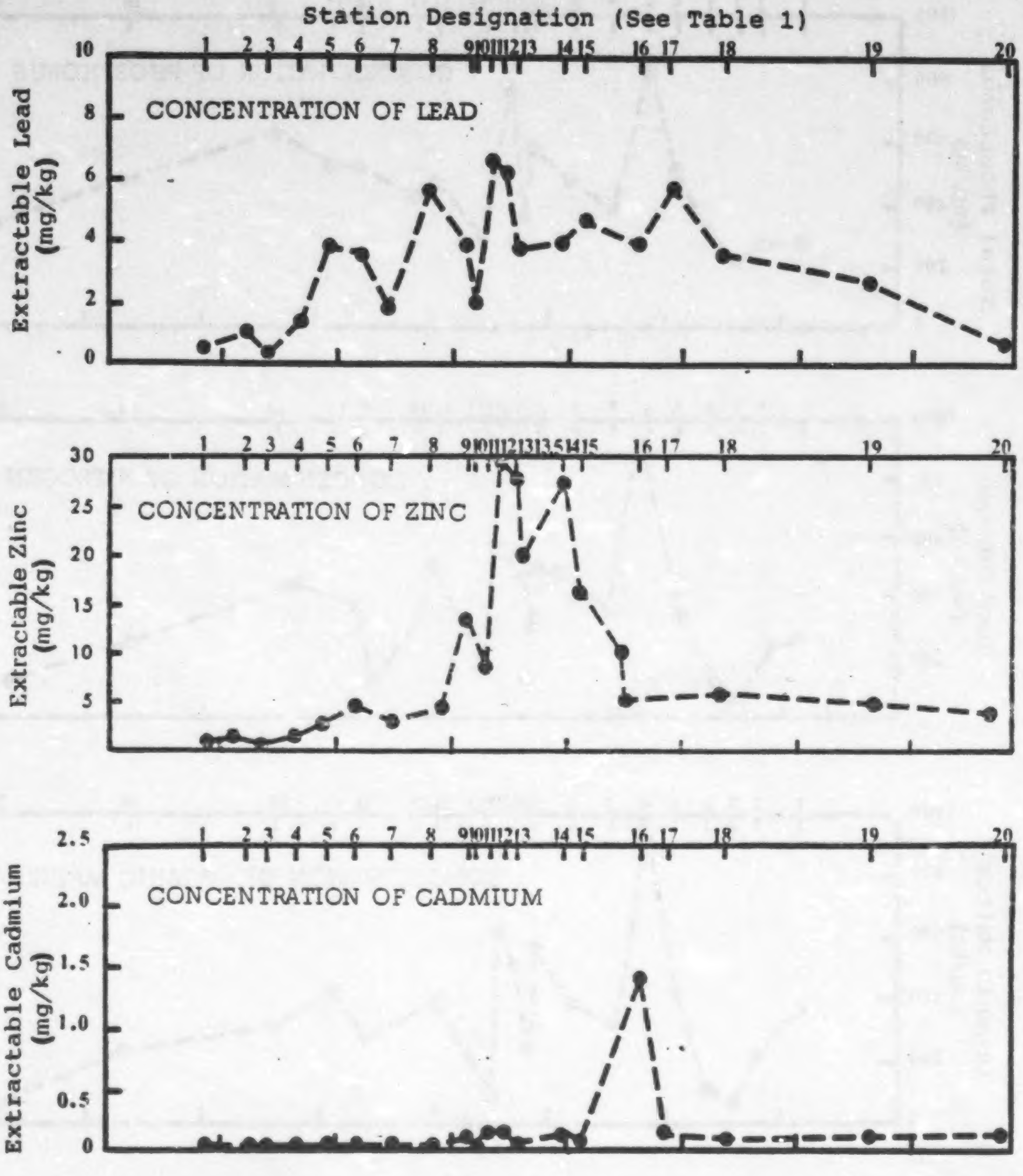

FIGURE 9. CONCENTRATIONS OF SELECTED CHEMICAL CONSTITUENTS IN BOTTOM SEDIMENTS OF SOUTH PLATTE RIVER ON FEBRUARY 24, 1981 NEAR DENVER, COLORADO.

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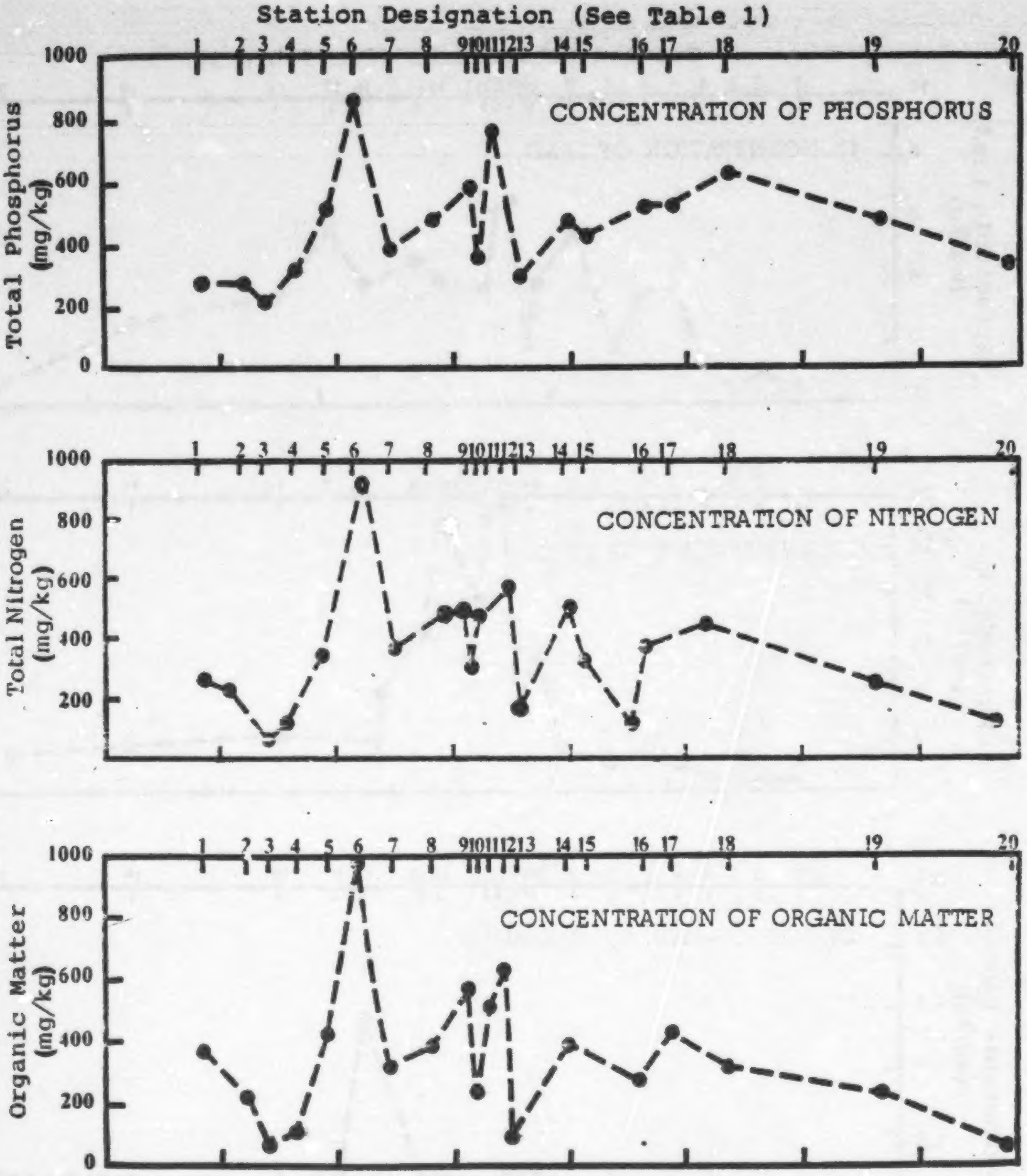

FIGURE 9. CONTINUED CONCENTRATIONS OF SELECTED CHEMICAL CONSTITUENTS IN BOTTOM SEDIMENTS OF SOUTH PLATTE RIVER ON FEBRUARY 24, 1981 NEAR DENVER, COLORADO.

8, and 11 were located below major tributary inflows which indicated a nonpoint origin of the lead in sediments observed at these locations. Also, these sites were characterized as being extensive depositional zones. The troughs which separate these 3 peaks coincided with areas of scour in the river channel. An extensive bottom deposit is located at Site 12, followed by areas of scour through to Site 15. Concentrations of zinc were more pronounced at these stations compared to upstream and downstream areas. Zinc and lead showed similar patterns and association to tributary sources. Although zinc concentrations dropped off rapidly in a downstream direction, lead concentrations remained high from this site downstream for about 15.5 miles to Site 19, at Henderson, Colorado.

The reach profile for cadmium was consistently low with the exception of an anomalously high peak observed at Site 16 (Figure 9). Values of cadmium at this same site upstream from the Denver metropolitan wastewater treatment plant discharge do not appear to be associated with treated wastewater effluent. Rather, by virtue of its location, it is surmised that it may have been associated with discharges from near upstream industrial facilities. It should be pointed out, however, that comparable cadmium concentration peaks were not observed downstream from two power plant facilities in the study reach (located upstream from Sites 5 and 10), although some indications of slightly elevated concentrations sometimes were noted. The cadmium concentration reach profile was quite different in pattern from those for lead and zinc and indicate consistently the point-source contributions affecting the profiles for this trace metal.

The stream-reach plot of total phosphorus was considerably different than that of lead and zinc. A base level of about 400 milligrams per kilogram (mg/kg) occurred throughout the reach with two prominent peaks in upstream areas and a third area of elevated concentrations in the downstream section of the river. The first peak at Site 6 occurred downstream of the Littleton/Englewood wastewater treatment plant and the second peak at Site 11 was located below the Lakewood wastewater treatment plant. A trough at Site 13 began where Cherry Creek entered the river at Confluence Park in an area of scour and a third peak at Site 18 coincided with a depositional area below the Metro Sewage District plant. Phosphorus remained high for 18.5 river miles until the downstream Site 20 at Brighton, Colorado. This trend of high phosphorus concentrations below wastewater treatment plant outfalls indicated an association of phosphorus with municipal point sources.

Stream-reach plots of total nitrogen and organic matter showed trends similar to phosphorus. Similarities in peaks and troughs were consistent throughout but with differences in magnitude. Organic matter varied greater than phosphorus in relative terms. A peak occurred at Site 17 instead of Site 18 for organic matter compared to total phosphorus, one station closer to the Metro plant discharge, and levels decreased more rapidly in a downstream direction. Although total nitrogen and organic matter are also components of urban runoff, the association with point sources was pronounced and related to depositional areas which occur in the river channel.

Organic matter, nutrients, and trace metals in the stream channel bottom exert an influence on the river through interactions between sediment particles and water passing over the sediment. Dissolved oxygen deficits can occur over sludge deposits at night when algae consume oxygen during respiration. Fish and other stream organisms require oxygen and could be adversely affected by dissolved oxygen depletion. Excessive nutrients in the water encourage algal growth which could exacerbate this problem. Heavy metals, such as lead, copper, zinc, and cadmium are toxic to fish and humans if excessive amounts are present in their bodies. Because trace metals associate strongly with particulate materials, bottom sediments can act as metal accumulators during periods of low velocities when the riverbed is a depository for incoming sediments, and these, as well as the sediment already in place, can serve as scavengers of dissolved metals and other constituents adsorbed on sediment particles. Such information was used to delineate areas of anomalously high concentrations and possible sources of these contaminants.

BENEFICIAL USE ANALYSIS

The South Platte River is a resource upon which many people depend for various beneficial uses of its water. As such, it should be protected to maintain the many uses to which it is applied. Beneficial uses of the river include fishing and other water-based recreation, agriculture, industrial applications and municipal water supply.

The Colorado Water Quality Control Commission has classified the segment of the South Platte River which corresponds to the study reach (Segment 14) as a Class 1, Warm Water Fishery, a Class 2 Recreation Stream, a Public Water Supply, and for Agricultural Use. The cities of Englewood and Thornton draw a portion of their water supply from the river. Major agricultural ditch headgates are located immediately downstream of the study area.

The section which follows discusses the effects of urban runoff on beneficial uses of the river. A detailed study of the ecological impact that urban runoff has on stream organisms was beyond the scope of this investigation. A comparison is made to the percent of time water-quality standards were exceeded during storm runoff and ambient streamflow conditions. A qualitative survey of aquatic life and the possible effects due to urban runoff are presented.

Percent Exceedence of Water-Quality Standards

The percentages of time water-quality standards were exceeded during both ambient and storm-runoff periods at the South Platte River at 50th Avenue during April 1980 through September 1981 are presented in Table 19. Monitoring data indicated temperature, pH and dissolved oxygen never exceeded standards during storms or ambient conditions.[10] Fecal coliform bacteria exceeded the standard 31 percent of the time during ambient conditions and 100 percent of the time during storm runoff.

Un-ionized ammonia values were estimated from total ammonia concentrations at prevailing pH and temperature conditions. This method is subject to error for storm runoff due to the highly variable nature of un-ionized ammonia. A temporary modification of the un-ionized ammonia standard of 0.1 mg/L (revised upward from 0.06 mg/L) was exceeded 31 percent of the time during ambient streamflow but was not estimated to have ever exceeded the standard during monitored storms.

A standard of 0.5 mg/L for nitrite and 10.0 mg/L for nitrate have been established for Segment 14 (Table 19). Nitrite exceeded this standard only briefly during ambient conditions. Nitrite did not exceed the standard during storm events monitored. Nitrate never exceeded the standard during either storm runoff or ambient conditions. Nitrite and nitrate storm event mean concentrations closely approximated minimum ambient concentrations (Table 14) and thus are not interpreted to be an urban runoff problem of significance.

The percent exceedence of stream standards for metals during both ambient and storm-runoff conditions is also listed in Table 19. With the exception of dissolved iron and manganese, all of the total metals exceeded stream standards 100 percent of the time during storms.

The standards for metals are referenced[11] as being total metals. An important note of caution must be realized when interpreting this conclusion drawn from comparing two separate data bases. In deriving values for metal standards, the mean value and the standard deviation were calculated based on monitoring data collected between July 1976 and June 1977 by the

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[10] Missing field data for temperature, pH and dissolved oxygen during January through June 1981 were estimated from "1981 Water Pollution Control Report," Environmental Health Service, City and County of Denver, 1982.

[11] Code of Colorado Regulations, 5 CCR 1002-8, 1981.

Table 19

PERCENT EXCEEDANCE OF WATER-QUALITY STANDARDS FOR AMBIENT AND STORM EVENT MEAN CONCENTRATIONS FOR APRIL 1980 THROUGH SEPTEMBER 1981 AT SOUTH PLATTE RIVER AT 50TH AVENUE

Water-Quality Variable	Stream Standard[1]	Units	Percent Exceedance	
			Ambient	Storm
Dissolved Oxygen	5.0	(mg/L)	0	0
pH	6.5-9.0	(S.U.)	0	0
Fecal Coliforms	2000	(#/100mL)	31	100
Un-ionized Ammonia	0.1	(mg/L)	31	0
Nitrite as N	0.5	(mg/L)	1.4	0
Nitrate as N	10.0	(mg/L)	0	0
Cadmium, Total	1	(μg/L)	41	100
Cadmium, Dissolved[2]			5.0	44
Copper, Total	25	(μg/L)	44	100
Copper, Dissolved[2]			4.0	0
Lead, Total	25	(μg/l)	29	100
Lead, Dissolved[2]			2.7	0
Iron, Total	1,000	(μg/L)	51	100
Iron, Dissolved	300	(μg/L)	3.4	0
Manganese, Total	1,000	(μg/L)	0	100
Manganese, Dissolved	50	(μg/L)	79	89
Zinc, Total	110	(μg/L)	27	89
Zinc, Dissolved[2]			2.7	0
Chloride	250	(mg/L)	1.6	0

[1] Section 3.8.0 of "Water Quality Standards and Stream Classification," Water Quality Control Commission, adopted April 6, 1981, Code of Colorado Regulations, 5 CCR 1002-8, 1981.

[2] No standard exists for dissolved form, percent exceedence calculated on stream standard for total form of same metal for comparison only.

Colorado Department of Health.[12] When the mean-plus-one-standard-deviation value was greater than criteria values, this value was assigned; otherwise the criteria value was used. In this manner, specific values were determined for Segment 14 of the South Platte River. The analytical methods and data base used to calculate a mean plus one standard deviation were not analysed using a total metals determination, as referenced[13] in EPA procedure 4.1.3. The Colorado Department of Health used an "acid soluble" analytical method for determination of stream metals concentrations; only a mild acid digestion is used in this procedure. Concentrations of metals occurring during high suspended solids conditions may tend to produce lower values using this procedure than if a total metals method were used.

Percent exceedance of dissolved metals which do not have an established standard were calculated for comparative purposes based on the stream standard for the total form of the metal and are listed in Table 19. The percent exceedence for dissolved metals under ambient conditions have also been presented in Table 19. Dissolved metals concentrations, especially during storms, may pose problems to public water supplies and to fish and other aquatic life and should be considered further as to their effect on the South Platte River.

Effects on Aquatic Life

Urban runoff contributes significant amounts of chemical substances to the South Platte River. Many of these are potentially toxic to aquatic life at the high concentrations found in urban runoff or may affect them through habitat alteration, reduction of food sources, or decreased dissolved oxygen levels. Also, sudden large additions of stormwater to the river may physically stress and displace aquatic life, especially early life stages of fish and benthos.

A qualitative survey of fish and benthic organisms was conducted in the South Platte River below Chatfield Dam to Henderson, Colorado (Figure 8) in an effort to assess the effect of urban runoff on aquatic biota. This survey was conducted by DRCOG with assistance from the EPA and Colorado Division of Wildlife. Sampling locations and data gathered appear in Table 20.

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[12] R.D. Anderson, "Summary Report on the Water Quality Investigation of the South Platte River: July 1, 1976-June 29, 1977," Water Quality Control Division, Colorado Department of Health, 1978.

[13] U.S. Environmental Protection Agency, Methods for the Chemical Analysis of Water and Wastes," Government Printing Office, Washington, D.C., EPA-600/4-079-020, 1979.

Table 20

BIOLOGICAL SURVEY SAMPLING LOCATIONS AND DATA COLLECTED ON NOVEMBER 17, 1981, IN THE SOUTH PLATTE RIVER

Site Name	Location	River Mile	Fish	Benthos
A	Below Chatfield dam	335	X	X
B	Near C-470 Bridge	333.6	X	
C	Near Cooley/Crawley Gravel	331.7	X	
D	Near Maplewood Avenue	330.9	X	
E	At Littleton gaging station (06710000)	328.9	X	X
F	Near Oxford Avenue Bridge	326.6	X	X
G	Near Florida Avenue Bridge (06711590)	322.7	X	X
H	Below Speer Blvd. Bridge (Confluence Park)	317.7	X	
I	At Denver gaging station (19th Street Bridge) (06714000)	317.2	X	X
J	At 50th Avenue gaging station (06714130)	314.3	X	X
K	Near Public Service Co. Cherokee Power Plant discharge	312.5	X	
L	Above Clear Creek (I-76 Bridge)	311.7		X
M	At Henderson gaging station (123rd Avenue Bridge) (06720500)	301.7		X

Fish were collected within 200 foot stretches of river at each sampling location by electroshocking and were identified, counted, and weighed. Benthic organisms were collected with a Surber sampler at all locations except 50th Avenue where a Ponar dredge was used.

Important Contaminants and Sources

Sources and relative quantities of water-quality contaminants important to aquatic life were identified. This was done through analysis of the results of the water-quality and bottom-sediment analyses and by examination of locations of major point source discharges along the river. Identification of sources was necessary to distinguish between influences imposed upon aquatic biota by point sources and urban runoff.

The dominant contaminants that were identified by DRCOG as being contributed by urban runoff were total suspended solids and total lead. High levels of suspended solids can adversely affect aquatic life by interfering with the activities of fish, smothering benthic organisms, and directly killing early life stages of fish. Urban runoff accounted for approximately 9 percent of the river flow for the basin studied, yet contributed about

76 percent of the total suspended solids load during April through September 1981 (Table 16). Lead is toxic to aquatic life, is known to produce sub-lethal deformaties in fish, and is readily accumulated in aquatic food chains. Loads of total lead entering the South Platte River were predominately from urban runoff, and concentrations in sediments increased throughout the heavily urbanized portions of the river segment studied (Figure 9).

Other pollutants identified include total organic carbon and ammonia which were primarily from municipal effluent discharges. Percent organic matter in sediments increased below both the Littleton/Englewood and Metro wastewater treatment plants (Figure 9). Both of these constituents are of concern to aquatic life.

Fish Fauna

A total of 17 species were collected in the South Platte River from the upstream site near the Highway C-470 bridge (RM 333.6) to the Public Service Company of Colorado Cherokee Power Plant discharge site (RM 312.5). The percent each fish species represented of the total catch at each station is presented in Table 21. Almost one-half of the number of species found were sportfish, though they only constituted a large proportion of the fish community below the Cherokee site. Also, with the exception of brown trout captured at the upstream four sampling locations and black bullheads, sportfish were small and probably still in first year's growth. The few largemouth bass collected averaged only five inches in length. It is thought that possible sources of some sportfish in the South Platte River are from lakes and ponds connected to it from both upstream and downstream directions, an example being Chatfield reservoir (See Figure 8). The presence of small sportfish could also be indicative of naturally breeding populations, but no mature adults were captured at any site for reasons unknown.

Urban runoff may affect fish populations in several ways. First of all, as is depicted in Figure 10, lower densities of fish were found in sites having predominantly sandy substrate. Only 0.098 fish/foot were captured at the Cooley/Crawley gravel Site (RM 331.7) where the river bottom was sand overlaid on cobbles. The greatest density was found below Confluence Park (RM 317.7), a diverse section including rubble, cobble, and a large drop structure and recreational kayak chute.

While the South Platte River as a High Plains stream naturally contained much unstable, shifting substrate creating poor fish habitat,[14] the condition may be exacerbated by additional inputs of sediment from urban runoff.

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[14] D.L. Probst, "The Warmwater Fishes of the Platte River System, Colorado, 1978-1980," prepared for the Colorado Division of Wildlife; Colorado State University, Fort Collins, Colorado, 1982.

Table 21

FISH SPECIES AS A PERCENTAGE OF TOTAL SAMPLE AT EACH SAMPLING LOCATION[1]

Species	Sampling Location[2] B	C	D	E	F	G	H	I	J	K
Black Bullhead *(Ictalurus melas)*	<1	2		1	1	1	<1			
Bluegill Sunfish *(Lepomis macrochirus)*				<1						6
Brown Trout *(Salmo trutta)*	<1	7	<1	<1						
Carp *(Cyprinus carpio)*				<1			15	<1		17
Channel Catfish *(Ictalurus punctatus)*	<1									
Creek Chub *(Semotilus atromaculatus)*	3	3	31	35	27	2	14	22	1	
Fathead Minnow *(Pimephales promelas)*	1	8	6	<1	9	2	54	47	93	4
Green Sunfish *(Lepomis cyanellus)*				<1	2	3	1	<1	4	8
Johnny Darter *(Etheostoma nigrum)*					1					
Largemouth Bass *(Micropterus salmoides)*	<1	2		<1			<1	<1		7
Longnose Dace *(Rhinichthys Cataractae)*	49	24	26	9	6	8	1	1		
Longnose Sucker *(Catostomus catostomus)*	31	49	36	33	22	75	10	14		4
Pumpkinseed Sunfish *(Lepomis gibbosus)*								<1		13
Sandshiner *(Notropis stramineus)*	2			2			<1	<1		
White Crappie *(Promoxis annularis)*							<1			24
White Sucker *(Catostomus commersoni)*	11	3	1	17	31	9	4	14	3	17
Yellow Perch *(Perca flavescens)*	3	2		2	1					
Total[3]	100	100	100	99	100	100	99	98	100	100

[1] <1 Indicates species comprised less than 1 percent of sample.

[2] Sampling locations are described in Table 20.

[3] Species comprising <1 percent of sample constitute difference between total and 100 percent.

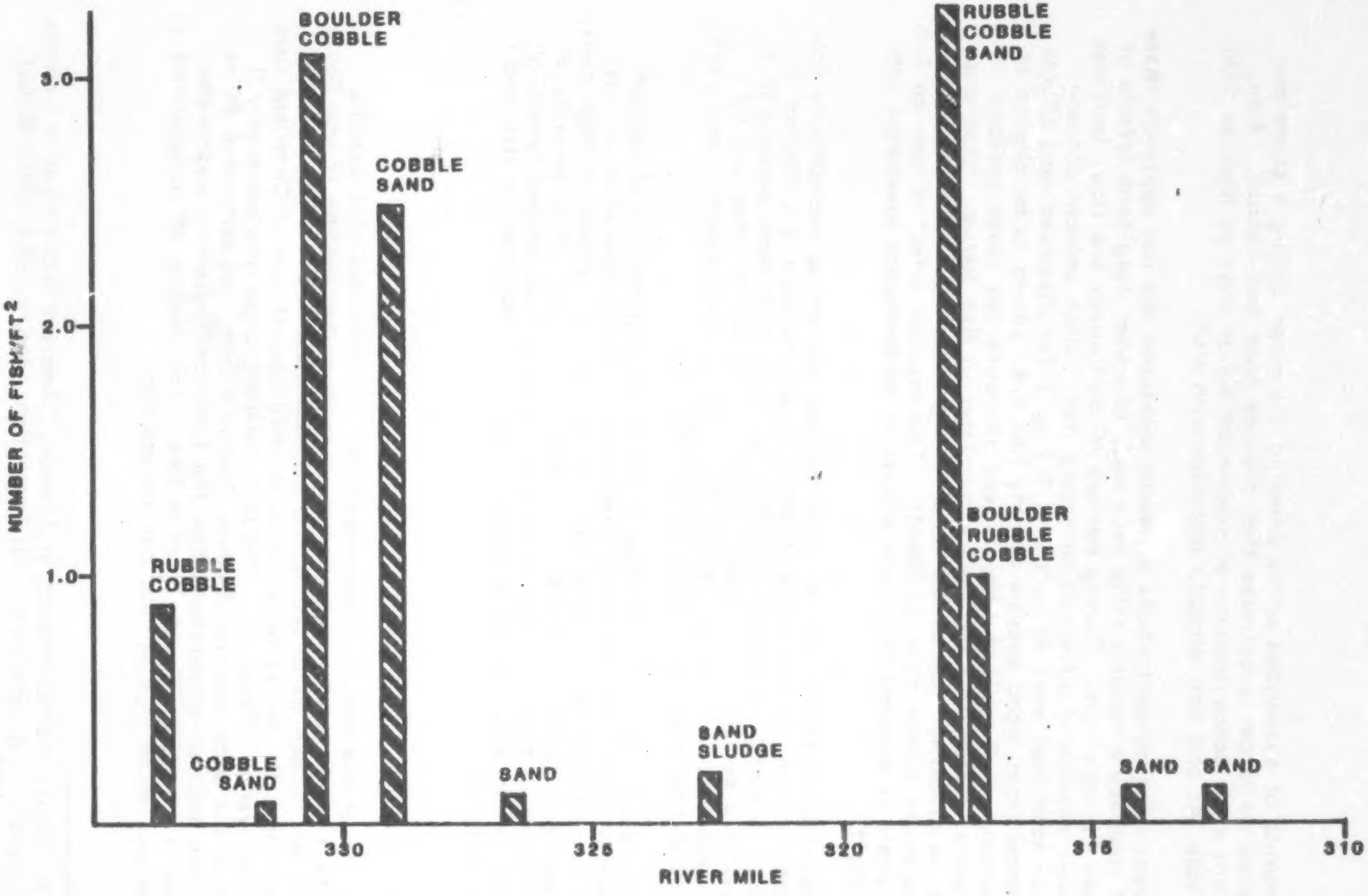

FIGURE 10. FISH DENSITY AND SUBSTRATE TYPE AT SAMPLING LOCATIONS IN SOUTH PLATTE RIVER.

Large amounts of suspended solids entering the river during a storm may be deposited on larger substrates that provide good fish habitat. Also, storm event mean concentrations of suspended solids were as high as 1430 mg/L (Table 14) and may directly interfere with fish.

Storm event mean concentrations of metals measured did not approach those reported from acute toxicity tests reviewed, however, long-term affects of metals may be important. During periods of continuous low flow, lead may reach levels capable of adversely affecting fish. Mean ambient concentrations of total lead were 30 µg/L and 9.7 µg/L for dissolved lead (Table 13); rainbow trout blood enzyme activity has been shown to be altered at concentrations of 13 µg/L.[15] Chronic lead exposure can cause scoliosis in fish (a spinal deformity), and lead accumulates in fish tissue. Lead was found to be primarily from urban runoff. Significant quantities of lead were also found within river sediments. The residual effect of lead on fish is an example of possible long-term effects of contaminants associated with urban runoff.

High flows during storms and at other periods may act to redistribute fish populations. While no data were collected to substantiate this finding in this study, it stands to reason that fish can only hold their position in a river against a certain upper water velocity. Beyond it, they will be washed downstream. Fish larvae may be killed by over-exertion and physical abuse during high-flow storm-runoff periods.

A possible benefit of increased flow is the scour and removal of oxygen demanding wastes below municipal discharges. The accumulation of this material may reduce food sources for fish through the growth of high densities of pollution-tolerant organisms of lower food value. High amounts of organic matter in sediments may also decrease dissolved oxygen levels in the water column and sediments below those levels required for fish and fish egg survival.

Benthic Organisms

The results of the benthic stream-reach survey indicated that benthic organisms are principally controlled by organic matter loading in the South Platte River. Clean water macroinvertebrates including mayflies, caddisflies, and black fly larvae were found at sites downstream of Chatfield Dam to Oxford Avenue (Table 20). Pollution tolerant organisms were only 8 percent of the total community below Chatfield Dam, but comprised 96 percent of the macroinvertebrates below the Littleton/Englewood wastewater treatment plant at the Florida Avenue Site. The density of sludgeworms at this site was quite high at 1488 per square foot.

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[15] U.S. Environmental Protection Agency, "Ambient Water Quality Criteria for Lead", U.S. Environmental Protection Agency, EPA 440/5-80-057, October, 1980.

Downstream of Florida Avenue the dominant groups found were sludgeworms, bloodworms, and nematodes. Below the Metro wastewater discharge at the site above Clear Creek, sludgeworms constituted 99 percent of the fauna and occurred in densities of 995 per square foot on cobble, and 2112 per square foot on gravel. Significant improvements in the fauna were not evident downstream at 123rd Avenue, Henderson, Colorado.

It is difficult to associate changes in the benthic fauna with effects of urban runoff. Benthic organisms appeared to be highly influenced by organic loading. However, deposition of sediment and organic matter from urban runoff would adversely affect the fauna and alter its structure. The extent to which this and other effects of urban runoff exert control on benthic populations could not be determined in this study.

SUMMARY AND CONCLUSIONS

The purpose of this receiving-water assessment was to present an analysis of the effect of urban runoff on the South Platte River in Denver. Urban runoff generated within the Denver metropolitan area can adversely impact the quality of water of the South Platte River and its tributaries. Results of the analysis indicated loads from urban runoff contributed significant amounts of sediments, bacteria, organic matter and trace metals to the river during storm events when compared to discharges from wastewater treatment plants over the same time period.

Concentrations of nitrite, nitrate and un-ionized ammonia during storm periods did not exceed stream standards and will not pose problems for aquatic life. Mean concentrations of total suspended solids during storm runoff exceeded mean ambient concentrations, sometimes by a factor of five. Total metals concentrations for lead, zinc, copper, cadmium, iron, and manganese during storm-runoff periods were greater than mean ambient concentrations and exceeded established stream standards 100 percent of the time. Effective control of these constituents in urban runoff would improve the quality of water of the South Platte River.

A comparison of the relative loading from point sources, baseflow and storm runoff were presented. Results indicated that total organic carbon, total nitrogen and total phosphorus loads were predominantly point source influenced. Total suspended solids and total lead loading of the South Platte River were shown to be predominantly influenced by the contributions from urban runoff.

Bottom-sediment profiles of selected constituents were defined from samples collected from the South Platte River. High concentrations of lead and zinc were observed in depositional areas downstream from major tributary inflows. This indicated that the source of these metals was primarily from the land surface within the basin. Total phosphorus, total nitrogen and organic matter were found in high concentrations in depositional areas downstream from wastewater treatment plant discharges. The cadmium reach profile indicated an association with industrial point source inputs. Sediments which are discharged into the river from both point and nonpoint sources accumulate in depositional areas and can later be resuspended during high streamflow periods. The influence of bottom sediments on water quality were discussed.

A surprising number of fishes and sportfish were collected from the South Platte River. These sportfish, though, were small in size and constituted a large proportion of the fauna at only one sampling location. Suspended solids and total lead were determined to be the primary contaminants associated with urban runoff which may pose problems for the aquatic biota. Short-term and long-term influences of suspended solids were noted. Habitat alteration due to suspended solids loading may decrease available fish habitat in the South Platte River. Also, ambient lead concentrations were found to be within a range capable of inducing long-term, chronic effects in fish. Insufficient data were gathered in this study to denote if adverse impacts on fish were evident from acute exposure to contaminants found in urban runoff.

Benthic organisms appeared to be controlled by organic loading from municipal wastewater discharges. It was difficult to relate changes in community composition along the river to the effects of urban runoff.

The interactions of pollutants, biota, and flow are complex. A habitat improvement program for the South Platte River in the Denver region should consider the control of urban runoff, whether this is accomplished in the river with channel improvements or within the basin by stormwater control measures.

The effects of urban runoff on beneficial uses of the South Platte River are difficult to quantify. Effects tend to relate more to the protection of the fishery status of the river rather than to public health concerns. The high concentrations of fecal coliform bacteria and dissolved metals should be considered as to their effect on downstream withdrawals of water for municipal water supplies and agricultural uses.

Effects of urban runoff on recreational uses, besides the fishery status of the river, are considered to be minimal. An assessment of the ecological impact of urban runoff on stream organisms was beyond the scope of this study. The relative effects of urban runoff as compared to point source discharges, and cumulative effects of both sources combined over time, should be considered to determine the impacts on water quality of receiving waters.

V. PREDICTING URBAN RUNOFF CHARACTERISTICS AND EFFECTS

While it is useful to know the results of the DRURP sampling programs described in the previous chapters, it would be more practical to be able to predict urban runoff effects. If a land use planner knew that certain land uses produced specific pollutant loadings, he would know whether mitigating measures were needed to prevent water quality problems. Similarly, the water quality planner could use a properly calibrated model to evaluate point/nonpoint source control tradeoffs.

This chapter presents the results of the DRURP modeling efforts. These begin with a discussion of desk-top models and methods that can be used to predict urban runoff characteristics. This is followed by methods to predict receiving water quality which includes both simple regression techniques and a complex simulation model. Finally, an effort to use weather radar to better understand rainfall patterns in the DRURP study area is discussed. Information from this effort was used to delineate "urban runoff priority control areas" that may prove useful in decisions to manage urban runoff.

PREDICTING URBAN RUNOFF CHARACTERISTICS

One objective of the urban runoff monitoring effort was to develop predictive desk-top planning models that can be easily applied by water quality planners, engineers, and others to estimate urban runoff pollutant characteristics in the DRURP study area. Several such models are presented in this section, along with instructions for their use and practical examples. These desk-top models can provide information that can be used to solve water quality problems related to urban runoff, for comparison of contaminant concentrations with stream standards, and in design of BMP programs.

Urban runoff data from this study were modeled by the USGS with DR3M (Distributed Routing Rainfall-Runoff Model). Unfortunately, this model is not compatible with HSPF (Hydrologic Simulation Program-Fortran) being used by DRCOG to predict instream influences. Results of the USGS's urban basin modeling are included in their NURP final report.

Model Development

Results of the rainfall-runoff and pollutant loading analyses discussed in Chapter III were used to develop a nomograph for estimating runoff, and

figures for estimating pollutant loading based upon basin percent effective imperviousness (PEI) or land use. Only data from thunderstorms and upslope rainstorms monitored were used; insufficient snowstorms were sampled to permit their modeling. A more detailed analysis of urban runoff characteristics and model development can be found in a technical memorandum available through DRCOG.

Rainfall-Runoff Nomograph

As was discussed in Chapter III, runoff was found to be curvilinearly related to rainfall at each basin. Runoff was also found to be well related linearly to PEI between basins. Based upon these relationships, runoff from rainstorms was plotted as a function of PEI and land use (Figure 11). This figure is identical to Figure 3 in Chapter III, and provides an estimate of storm runoff from intervals of rain from 0.1 to 2.5 inches. Examples and limitations of the use of Figure 11 are covered in a subsequent section of this chapter.

Pollutant Loading Graphs

Unit-area pollutant loadings in pounds per acre (lbs/ac) as a function of runoff were not found to be related to basin PEI or land use. However, loading tended to be similar for pairs of sites of similar land use (Chapter III). This is evident in Figure 5 which shows the slopes of linear regression equations derived between unit-area pollutant loading in lbs/ac and storm runoff for selected constituents from basins of a single land use. The slopes of these equations represent average unit-area loadings of pollutants per unit of runoff.

While loading as a function of runoff was not well related to PEI, loading as a function of rainfall was found to vary in a predictable manner to PEI. A greater percentage of runoff was generated per rainfall amount on the average in basins of high PEI. Even though loads per runoff amount did not vary directly with basin PEI, more pollutant load was usually produced as PEI increased due to increased runoff generated. That is, because the percentage of rainfall occurring as runoff varied directly with basin PEI, loading was related to rainfall and PEI. Average loadings per inch of rainfall for the five constituents in Figure 5 appear in Table 22. **Linear regression analysis between these variables and basin PEI yielded strong relationships for all constituents monitored.**

Pollutant loading and rainfall-runoff relationships are shown for total lead in Figure 12. The relationships for total lead exemplify those for the remaining constituents. This figure depicts the basis used to create graphs for estimating loads presented later. Unit-area loading of lead per runoff-inch (lbs/acre/runoff-inch) was not found to be well related to basin PEI. However, as the percentage of rainfall occurring as runoff was directly related to PEI, loading of lead (lbs/ac) was directly related to rainfall and basin PEI.

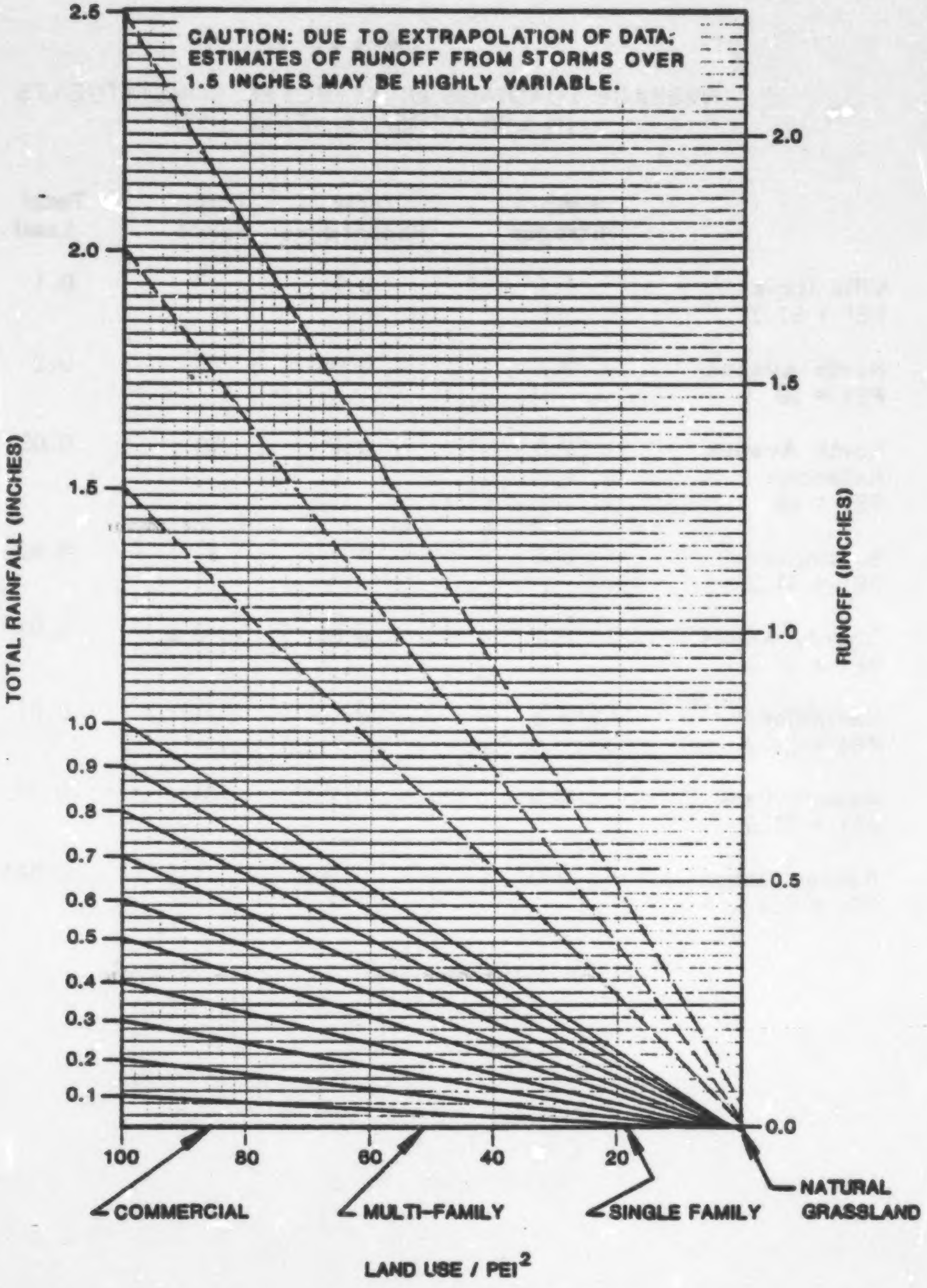

FIGURE11. NOMOGRAPH FOR ESTIMATING RAINSTORM RUNOFF.[1]

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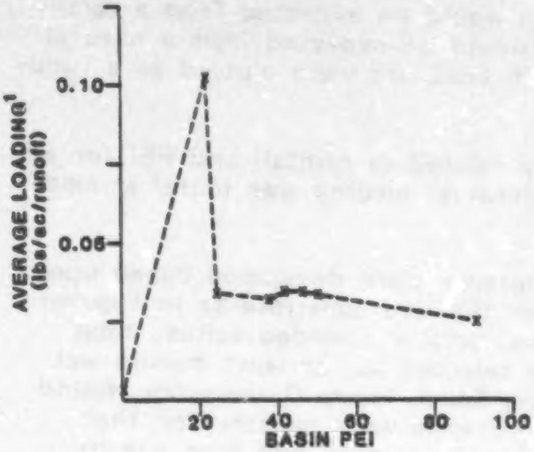
[1] SEE TEXT FOR DISCUSSION OF USES , LIMITATIONS.

[2] LAND USES CORRESPOND TO REGIONAL AVERAGES FROM ALLEY AND VEENHUIS, 1979.

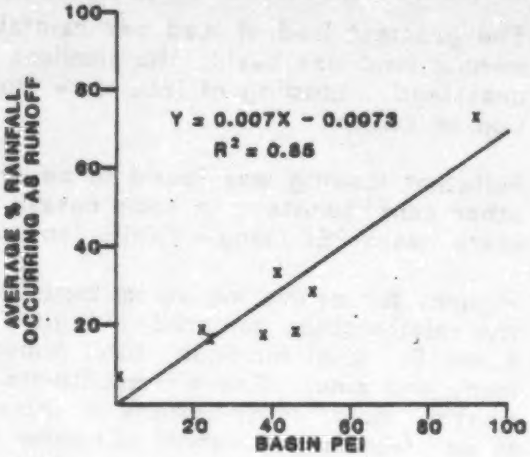
Table 22

AVERAGE LOADINGS OF SELECTED CONSTITUENTS IN LBS/ACRE/RAINFALL-INCH

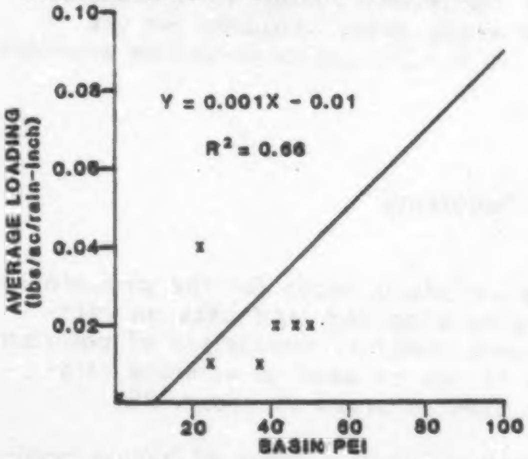
	Total Nitrogen	Total Phosphorus	Total Solids	Total Lead	Total Zinc
Villa Italia PEI = 91.2	1.1	0.1	37	0.1	0.1
North Avenue PEI = 50	0.4	0.04	30	0.2	0.2
North Avenue Retention PEI = 46	0.5	0.1	18	0.02	0.03
Southglenn PEI = 41.3	0.2	0.1	37	0.02	0.02
Cherry Knolls PEI = 37.5	0.1	0.02	8.6	0.01	0.01
Northglenn PEI = 23.9	0.2	0.03	27	0.01	0.01
Asbury Park PEI = 21.5	0.5	0.1	64	0.04	0.04
Rooney Ranch PEI = 0.6	0.04	0.005	5.0	0.001	0.001



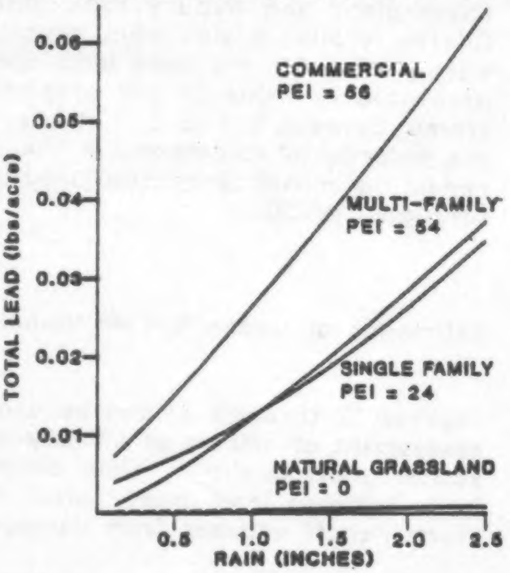
UNIT-AREA LOADING OF TOTAL LEAD PER RUNOFF AMOUNT AS A FUNCTION OF PEI.



RELATIONSHIP BETWEEN PERCENTAGE OF RAINFALL OCCURRING AS RUNOFF AND BASIN PEI.



UNIT-AREA LOADING OF LEAD PER RAINFALL AMOUNT AS A FUNCTION OF PEI.



UNIT-AREA LOADING OF LEAD AS A FUNCTION OF RAINFALL FOR EACH LAND USE TYPE.

FIGURE 12. DEMONSTRATION OF RAINFALL-RUNOFF AND POLLUTANT LOADING RELATIONSHIPS FOR TOTAL LEAD (SEE TEXT FOR EXPLAINATION).

[1] SLOPE OF EQUATION FROM LINEAR REGRESSION ANALYSIS BETWEEN LOADING (lbs/acre) AND RUNOFF (inches).

The greatest load of lead per rainfall-inch would be expected from a commercial land use basin; the smallest load would be expected from a natural grassland. Loading of lead data from each land use were plotted as a function of rainfall.

Pollutant loading was found to be directly related to rainfall and PEI for all other constituents. In some cases, the greatest loading was found at moderate basin PEI (single family land use).

Figures for estimating storm loads of pollutants were developed based upon the relationships depicted in Figure 12 for the five constituents in Figures 4 and 5: total nitrogen, total phosphorus, total suspended solids, total lead, and zinc. These constituents were selected as, at least during wet months, major contributions of them to the South Platte River were found to be from urban runoff (Chapter IV). Graphs were constructed that estimate unit-area loading in lbs/ac based upon rainfall and land use by solving linear regression equations expressing loading in lbs/ac as a function of runoff (Table 23) with regression equations expressing runoff as a function of rainfall (Table 24). Data from the pairs of single family (Northglenn and Asbury Park Retention) and multi-family (Southglenn and Cherry Knolls) basins were combined, since it was determined that loadings were similar for the same land use (Figure 5). The resulting equations are presented in Table 25 and graphed in Figures 13 to 17 for a range of rainstorms between 0.1 to 2.5 inches. This range was chosen as it includes the majority of rainstorms in the DRURP study area. Figures for the remaining constituents monitored appear in a technical memorandum available through DRCOG.

Estimation of Urban Runoff Volume and Pollutants

Figures 13 through 17 can be used in a variety of ways for the preliminary assessment of effects of already-existing or proposed land uses on rainstorm-runoff quality. They permit a quick, relative comparison of pollutant loads between land uses. Also, Figure 11 can be used to estimate rainstorm-runoff volumes from various land uses or areas of known PEI.

Due to the limited number of storms sampled, small number of basins monitored, and large variability found in pollutant loading, application of these figures and data outside of the DRURP study area is not encouraged. It was originally thought that results of this study could be applied to other regions of similar climate and geographical characteristics. The above mentioned factors precluded this. Also, these figures were derived from data from small, developed basins. They should not be used to estimate runoff and loads from large undeveloped basins (greater than 1000 acres).

The following restrictions apply to the predictive figures in this section.

Table 23

LINEAR REGRESSION EQUATIONS EXPRESSING UNIT-AREA POLLUTANT LOADING (LBS/ACRE) AS A FUNCTION OF RAINSTORM RUNOFF (INCHES) FOR DATA FROM BASINS WITH SIMILAR LAND USES COMBINED

(Equations are in the Form: Y=mX+b)

Constituent	Land Use[1]	Slope	Intercept	R^2[2]	Degrees of Freedom
Total Nitrogen	C	0.453	0.163	0.68	10
	MF	0.591	0.011	0.67	16
	SF	1.219	-0.011	0.66	12
	NG	0.567	-0.001	0.98	5
Total Phosphorus	C	0.051	0.022	0.15*	20
	MF	0.137	0.0004	0.54	22
	SF	0.243	-0.001	0.48	19
	NG	0.086	-0.001	0.99	5
Total Suspended Solids	C	39.01	7.120	0.15*	20
	MF	66.01	0.818	0.30	22
	SF	388.3	2.510	0.54	20
	NG	85.08	-0.772	0.99	5
Total Lead	C	0.027	0.005	0.40	20
	MF	0.036	0.001	0.39	22
	SF	0.039	0.003	0.22	20
	NG	0.003	0.0002	0.73	5
Total Zinc	C	0.035	0.008	0.47	20
	MF	0.035	0.001	0.41	21
	SF	0.061	0.001	0.44	20
	NG	0.013	0.00004	0.99	5

[1] Abbreviations of land use are as follows:
C = Commercial
MF = Multi-Family
SF = Single Family
NG = Natural Grassland

[2] All coefficients of determination are significnt at 95% level of confidence except those marked with an asterisk (*) which are significant at the 90% level.

Table 24

CURVILINEAR (POWER) REGRESSION EQUATIONS EXPRESSING RAINSTORM RUNOFF (INCHES) AS A FUNCTION OF RAINFALL (INCHES) FOR DATA FROM BASINS WITH SIMILAR LAND USES COMBINED

(Equations are in the Form: $Y=bX^m$)

Land Use	Slope	Coefficient	R^2	Degrees Of Freedom
Commercial	1.087	0.822	0.98	21
Multi-Family	1.278	0.307	0.77	29
Single Family	1.372	0.232	0.90	32
Natural Grassland	0.777	0.035	0.18[1]	6

[1] Coefficient of determination not statistically significant at 95% level of confidence.

Table 25

EQUATIONS EXPRESSING UNIT-AREA POLLUTANT LOADING (L) (LBS/ACRE) AS A FUNCTION OF RAINFALL (R) (INCHES) FOR DATA FROM BASINS WITH SIMILAR LAND USES COMBINED

Constituent	Commercial	Multi-Family
Total Nitrogen	$L = 0.163 + 0.372R^{1.087}$	$L = 0.011 + 0.181R^{1.278}$
Total Phosphorus	$L = 0.022 + 0.042R^{1.087}$	$L = 0.0004 + 0.042R^{1.278}$
Total Suspended Solids	$L = 7.120 + 32.07R^{1.087}$	$L = 0.818 + 20.25R^{1.278}$
Total Lead	$L = 0.005 + 0.022R^{1.087}$	$L = 0.001 + 0.011R^{1.278}$
Total Zinc	$L = 0.008 + 0.029R^{1.087}$	$L = 0.001 + 0.011R^{1.278}$

Constituent	Single Family	Natural Grassland
Total Nitrogen	$L = -0.011 + 0.283R^{1.372}$	$L = -0.001 + 0.020R^{0.777}$
Total Phosphorus	$L = -0.001 + 0.056R^{1.372}$	$L = -0.001 + 0.003R^{0.777}$
Total Suspended Solids	$L = -18.000 + 90.08R^{1.372}$	$L = -0.772 + 2.978R^{0.777}$
Total Lead	$L = 0.003 + 0.009R^{1.372}$	$L = 0.0002 + 0.0001R^{0.777}$
Total Zinc	$L = 0.001 + 0.014R^{1.372}$	$L = 0.00004 + 0.0005R^{0.777}$

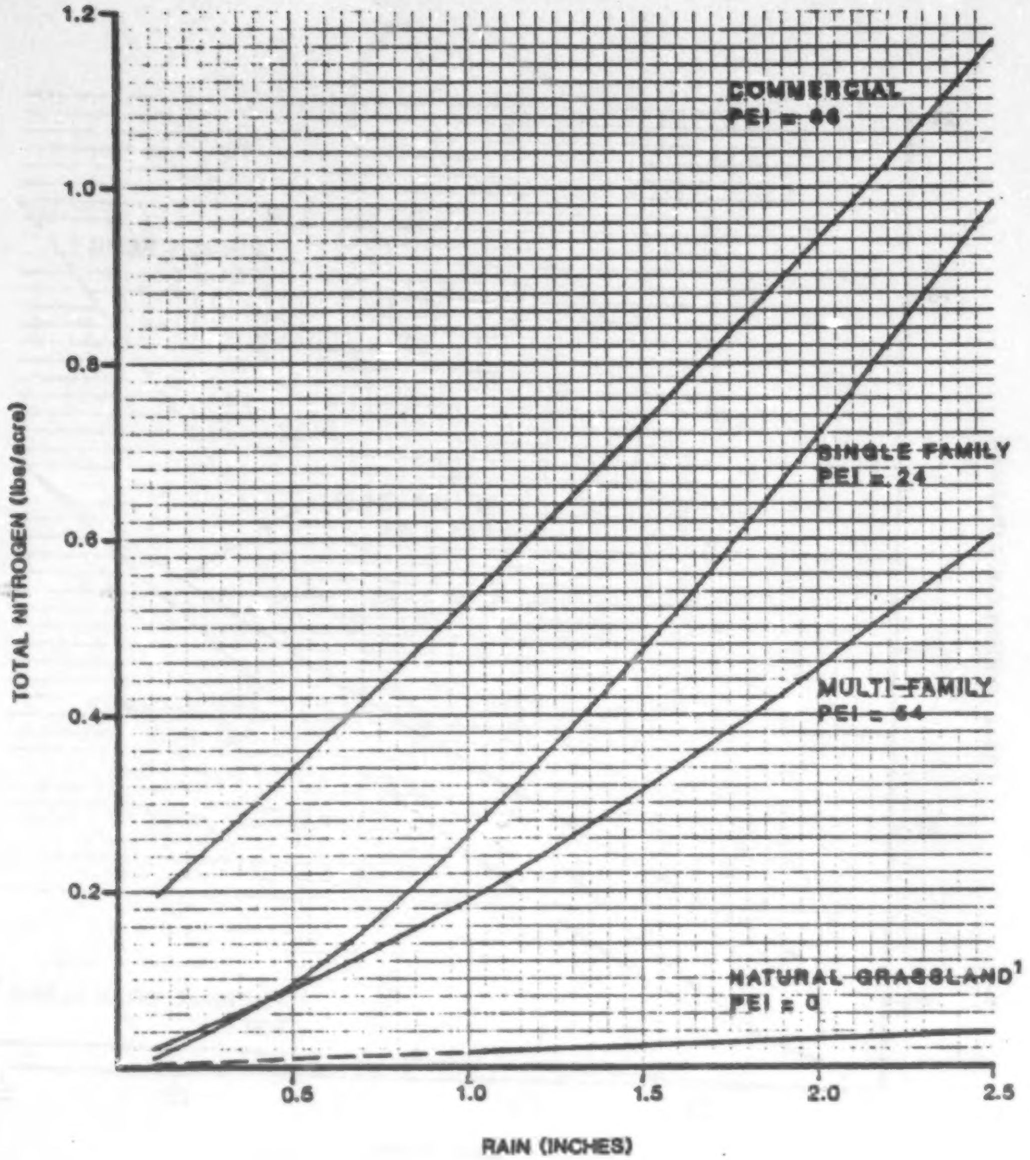


FIGURE 13, GRAPH RELATING UNIT-AREA LOADING OF TOTAL NITROGEN (lbs/acre) TO RAINFALL (inches). (EQUATIONS FOR CURVES ARE CONTAINED IN TABLE 13).

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

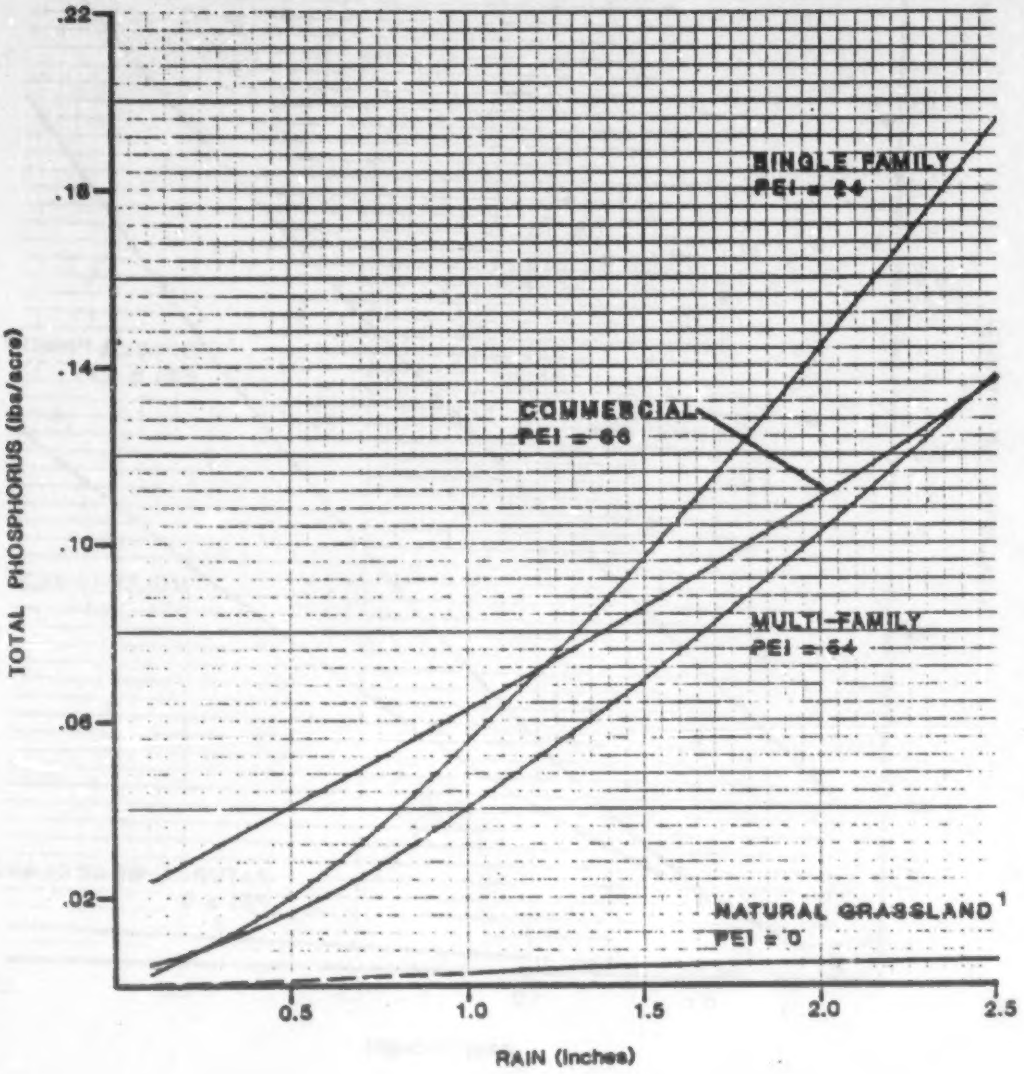


FIGURE 14. GRAPH RELATING UNIT-AREA LOADING OF TOTAL PHOSPHORUS (lbs/acre) TO RAINFALL (inches). (EQUATIONS FOR CURVES ARE CONTAINED IN TABLE.)

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

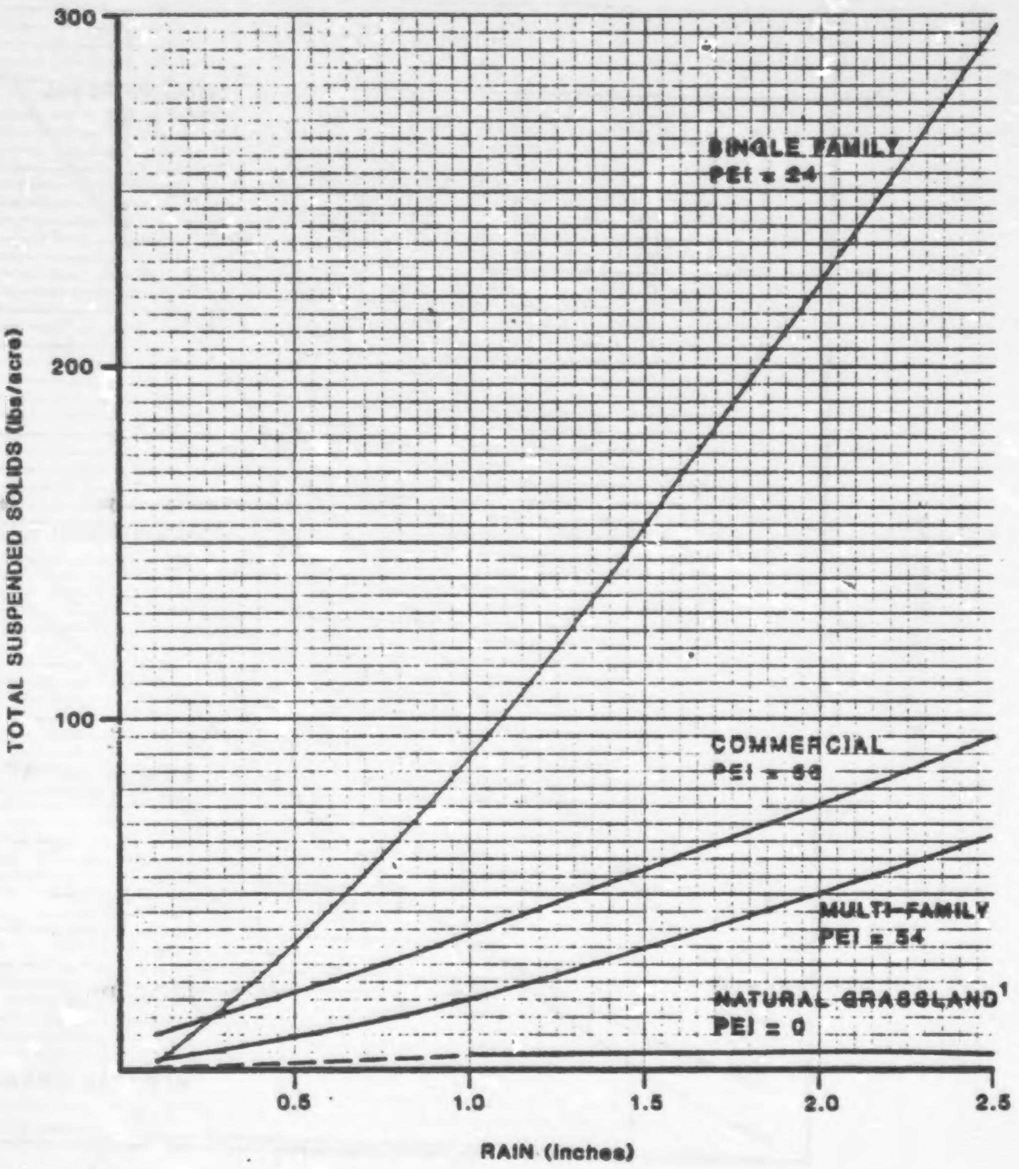


FIGURE 15. GRAPH RELATING UNIT-AREA LOADING OF TOTAL SUSPENDED SOLIDS (lbs/acre) TO RAINFALL (inches). (EQUATIONS FOR CURVES ARE CONTAINED IN TABLE 13.)

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

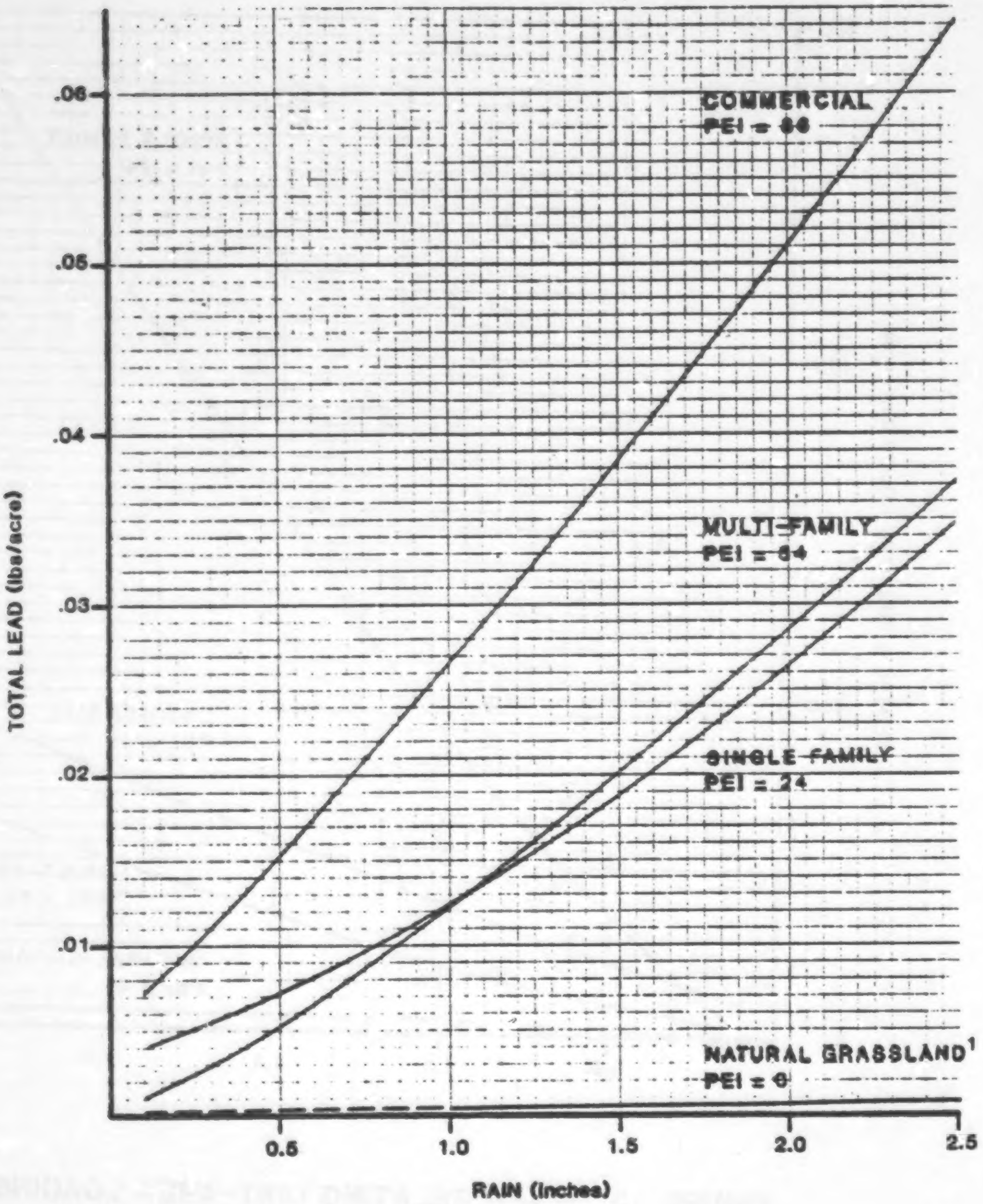


FIGURE 16. GRAPH RELATING UNIT-AREA LOADING OF TOTAL LEAD (lbs/acre) TO RAINFALL (inches). (EQUATIONS FOR CURVES ARE CONTAINED IN TABLE 13.)

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

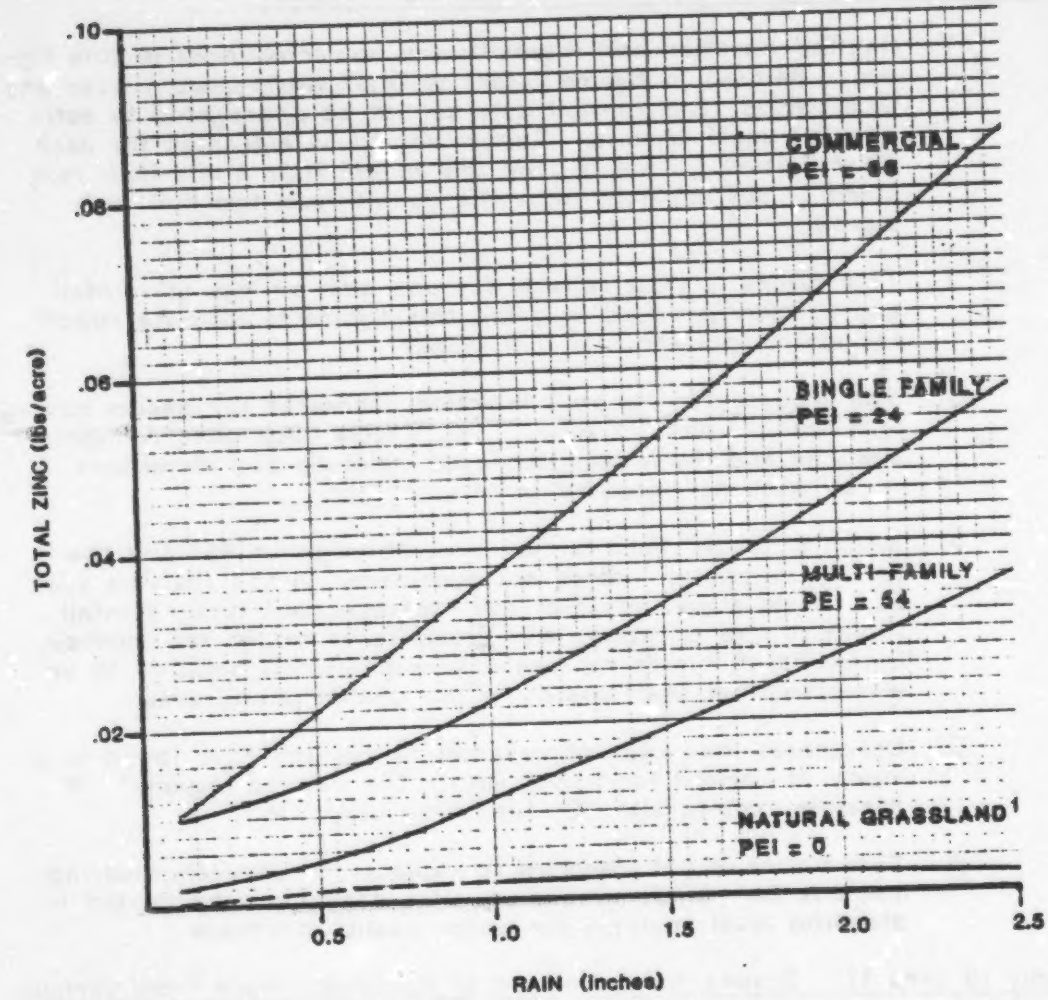


FIGURE 17. GRAPH RELATING UNIT-AREA LOADING OF TOTAL ZINC (lbs/acre) TO RAINFALL (inches). (EQUATIONS FOR CURVES ARE CONTAINED IN TABLE 13.)

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

Figure 11. Nomograph for Estimation of Rainstorm Runoff:

1. Rainfall duration and intensity are not considered in this figure. Rainfall in figure refers to total storm amount over any time period, and rainfall data cannot be aggregated to estimate a runoff amount. Runoff has to be estimated for each rainfall level. That is, the the runoff from a one-inch rainstorm is not equal to twice the runoff from two half-inch storms;

2. This figure is most reliable for one inch or less of rainfall and caution is urged in using this figure to estimate runoff for storms greater than 1.5 inches;

3. The accuracy of runoff prediction decreases for basins having less than 10 percent PEI. Runoff from such sites is highly variable and dependent upon soil moisture and conditions which were not included in this analysis;

4. Specific runoff amounts may vary throughout PEI and the land uses due to factors not considered in the analysis such as: basin slope, residual soil moisture, soil type, rainfall intensity and duration, and presence of frozen soil surface. Estimates of runoff represent average runoff amounts to be expected from small basins in the DRURP study area;

5. Designated land uses correspond to average PEIs found in a study of various land uses within the Denver region.[6] If possible, known site PEI should be used; and,

6. This figure is not intended to replace standard engineering methods for runoff prediction. Its use should be limited to planning level analysis for water quality purposes.

Figures 13 thru 17. Graphs for Estimation of Rainstorm loads from Various Land Uses:

1. Rainfall data can not be aggregated over time. Loads must be estimated for each rainstorm size. For example, the load from a one-inch rainstorm is not equal to twice the load from a half-inch storm;

2. These figures are most accurate for rainstorms of one inch or less, but can only be used with a minimum of 0.1 inches of rain;

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[16] William M. Alley and Jack E. Veenhuis, "Determination of Basin Characteristics for an Urban Distributed Routing Rainfall-Runoff Model," Presented to Storm Water Management Model Users Group, Montreal, Canada, May 24-25, 1979.

3. Caution is urged in using these figures to predict loads from natural grasslands from rainstorms of one-inch or less. Runoff may only be produced from small storms in such areas when either saturated or frozen soil conditions exist;

4. The curve labelled "single family" in these figures was derived from data from high density developments (3-6 dwelling units/acre). This curve should not be used to estimate loads from low-density single family developments; and,

5. Actual rainstorm loads may vary depending upon residual soil moisture, antecedent dry days, storm characteristics, and other factors not accounted for in this analysis.

The following information can be gathered from Figure 11 and Figures 13 through 17:

- an estimate of individual rainstorm runoff volume and load;
- an estimate of individual rainstorm event mean concentration;
- an estimate of annual rainstorm runoff volume and load; and,
- an estimate of annual average rainstorm event mean concentration.

The use of Figure 11 is demonstrated in Figure 18. In this example, it is desired to estimate runoff in inches produced from an inch of rain on a single family development. To use the nomograph, use the following steps:

1. Locate 1.0 inch precipitation on left vertical axis labelled "Total Rainfall";

2. Proceed down and to the right along line associated with 1.0 inch total rainfall, stop above point on horizontal axis below (labelled "Land Use/PEI") designated single family;

3. Draw a horizontal line from this intersection straight across to right vertical axis labelled "runoff";

4. Read runoff amount (approximately 0.14 inches runoff).

The use of Figures 13 through 17 is illustrated in Figure 19. Loads are estimated using the same procedure for each of these graphs. To estimate a load from a given rainfall, draw a vertical line up from desired level of rainfall to appropriate line of designated land use. Draw a line horizontally from the intersection to the left hand axis labelled "Total Lead". Read unit-area load (lbs/ac) off of this axis. In the example illustrated in Figure 19, a one-inch rainstorm will produce 0.027 lbs/ac of total lead from commercial land use.

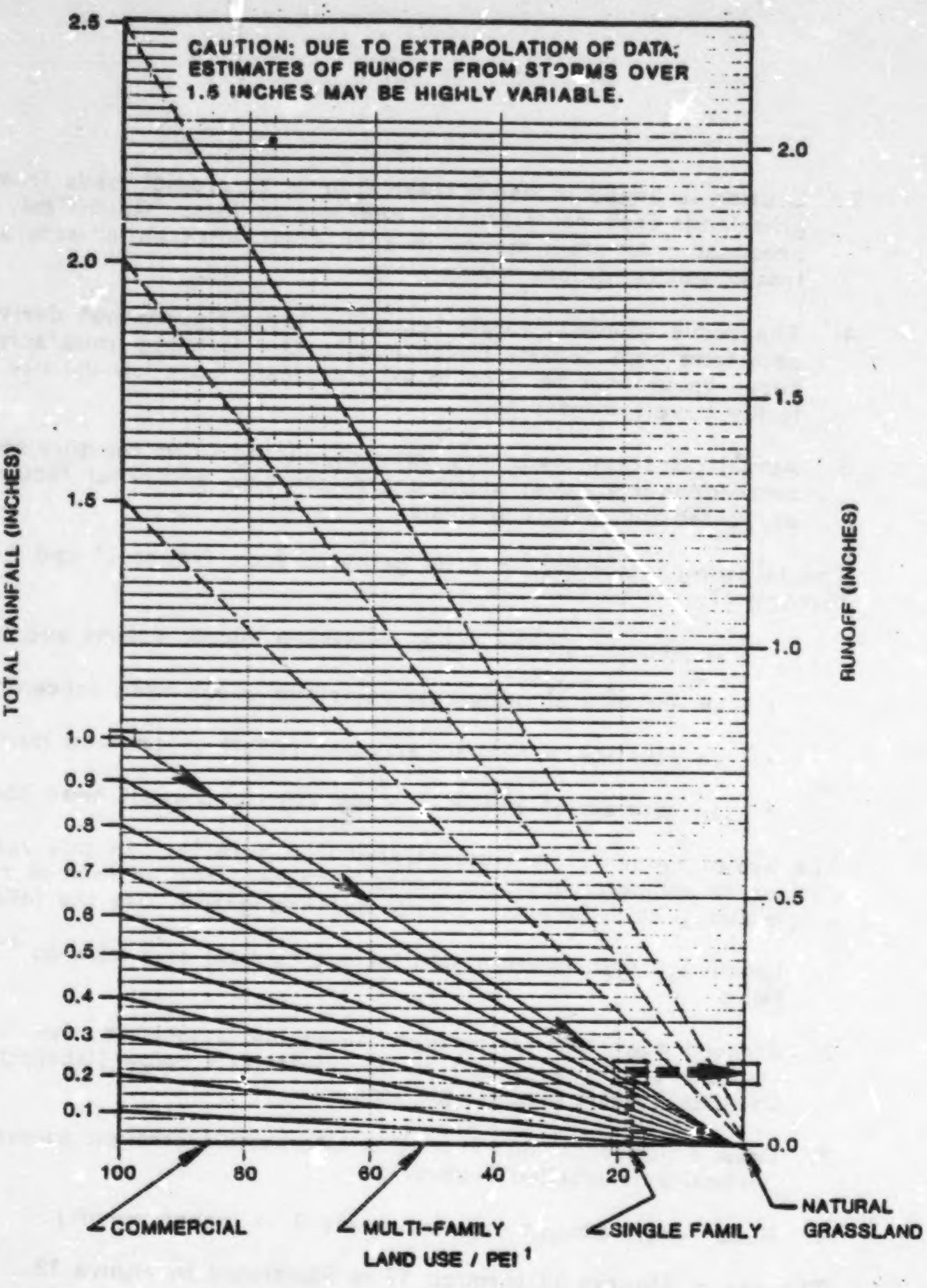

FIGURE 18. DEMONSTRATION OF THE USE OF RAINFALL-RUNOFF NOMOGRAPH (FIGURE 11). IN THIS EXAMPLE, 1.0 INCHES OF RAIN WILL PRODUCE 0.14 INCHES RUNOFF FROM SINGLE FAMILY LAND USE. (SEE TEXT FOR DETAILED EXPLAINATION.)

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[1] LAND USES CORRESPOND TO REGIONAL AVERAGE AND WERE OBTAINED FROM ALLEY AND VEENHUIS (1979) STUDY.

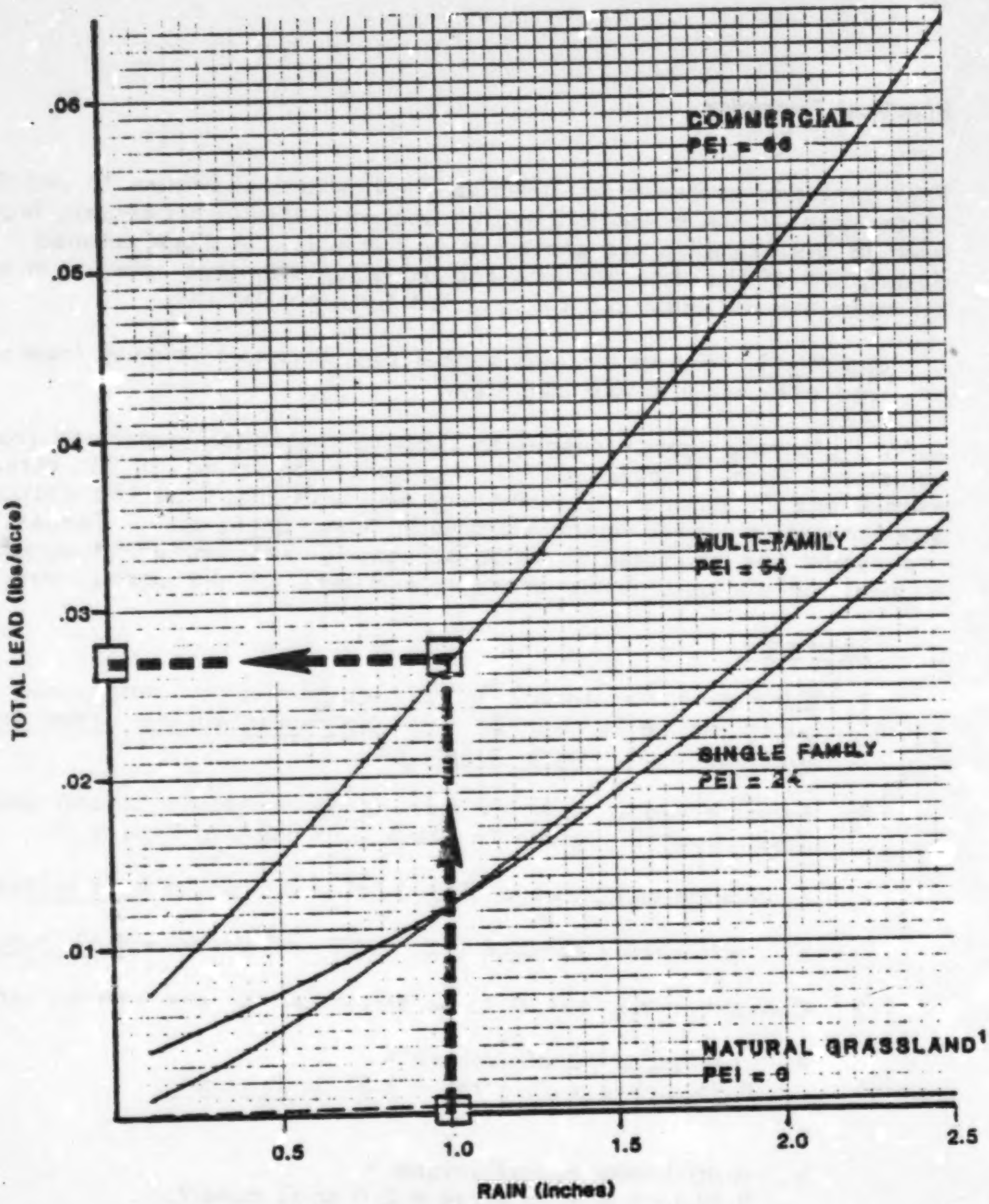

FIGURE 19. DEMONSTRATION OF THE USE OF POLLUTANT LOADING GRAPHS (FIGURES 13-17). IN THIS EXAMPLE, 1.0 INCHES OF RAIN WILL PRODUCE 0.027 lbs/acre TOTAL LEAD. (SEE TEXT FOR DETAILED EXPLANATION.)

[1] FORMATION OF RUNOFF AND LOAD BELOW 1.0 INCHES RAINFALL IS HIGHLY VARIABLE.

Practical Examples

Four problems exemplifying practical applications of Figure 11 and Figures 13 through 17 are presented in this section. Useful conversion factors used in the examples are contained in Table 26. A more detailed description of the data analysis and model development appears in a technical memorandum which can be obtained through DRCOG.

Example 1. Estimation and comparison of runoff volumes from various land uses for a single rainstorm.

A local planning agency wishes to compare the runoff generated from a 1.0 rainstorm from a proposed development consisting of 25 acres commercial and 75 acres multi-family land use with that from the undisturbed site for use in a preliminary stormwater management plan. Percent effective impervious was estimated to be 80 percent for the commercial acreage, 40 percent for the multi-family acreage, and zero for the undisturbed site.

Solution:

1. Estimate runoff from 1.0 inch rainstorm from undisturbed site using Figure 11 and PEI = 0: No runoff will be formed from 1.0 inch storm on natural grassland.

2. Estimate runoff from 1.0 inch rainstorm from proposed development based upon PEI given for each land use and Figure 11:

   a. commercial acreage (PEI = 80) will produce 0.65 inches runoff;

   b. multi-family acreage (PEI = 40) will produce 0.32 inches runoff.

3. Convert inches runoff to acre-feet (ac-ft) and sum for land uses:

   a. commercial runoff volume =
   $\frac{0.65 \text{ inches} \times 25 \text{ acres}}{12}$ = 1.35 ac-ft runoff;

   b. multi-family runoff volume =
   $\frac{0.32 \text{ inches} \times 75 \text{ acres}}{12}$ = 2.0 ac-ft runoff;

   c. total runoff = 1.35 ac-ft + 2.0 ac-ft = 3.35 ac-ft.

4. Compare runoff generated from 1.0 inch rainstorm before and after developement:

   undeveloped area = 0.00 ac-ft runoff;
   developed area = 3.35 ac-ft runoff.

Table 26

USEFUL FORMULAS FOR LOAD AND RUNOFF CONVERSIONS

RUNOFF CONVERSIONS:

TO OBTAIN	FROM	USE FORMULA
cubic feet runoff(cu.ft.)	inches runoff	cu.ft. = inches x acres x 3630
acre-feet runoff (ac-ft)	inches runoff	$\text{ac-ft} = \dfrac{\text{inches x acres}}{12}$
gallons runoff(gal.)	inches runoff	gal. = inches x acres x 27,154
acre-feet runoff (ac-ft)	cubic feet runoff	$\text{ac-ft} = \dfrac{\text{cu.ft.}}{43,560}$

LOAD CONVERSIONS:

Total pounds pollutant	pounds/acre pollutant	total pounds = (lbs/acre) x acres
Storm event mean concentration (EMC) in mg/L	runoff volume, load	$\text{EMC} = \dfrac{\text{(lbs/acre) x acres}}{\text{cu.ft. runoff}} \div (6.245 \times 10^{-5})$
Average storm event mean-concentration (AEMC) in mg/L	runoff volumes, loads for all storms	$\text{AEMC} = \dfrac{\text{total lbs. pollutant}}{\text{cu.ft. runoff for all storms}} \div (6.245 \times 10^{-5})$

METRIC CONVERSIONS:

gallons	**liters**	**1 gallon = 3.785 liters**
pounds	**grams**	**1 pound = 453.6 grams**

Conclusions:

No runoff will be produced from the natural grassland by a one-inch rainstorm. However, once developed, a one-inch rainstorm will produce an estimated 3.35 acre-feet of runoff from the 100 acres.

Example 2. Estimation and comparison of pollutant loading between land uses for a single rainstorm.

A local management agency desires to assess the possible effects of a proposed single family development (6 dwelling units/acre) adjacent to a suburban lake on the lake's water quality. The development is to be 500 acres and the land is presently a natural grassland. It is desired to estimate how much additional total nitrogen and total phosphorus will be added to the lake from runoff from a one-half inch rainstorm.

Solution:

1. Estimate unit-area loads of total nitrogen and phosphorus (in lbs/ac) from one-half inch rainstorm for the undeveloped grassland site using Figures 13 and 14 and line labelled "natural grassland":

   a. total nitrogen = 0.02 lbs/ac;

   b. total phosphorus = 0.002 lbs/ac.

2. Calculate total storm load in lbs. for 500 acre grassland using formula in Table 26:

   a. total storm load total nitrogen =
      0.02 lbs/ac x 500 acres = 10 lbs;

   b. total storm load total phosphorus =
      0.002 lbs/ac x 500 acres = 1.0 lb.

3. Estimate unit-area loads of total nitrogen and phosphorus in (lbs/ac) from one-half inch rainstorm for developed site using Figures 13 and 14 and line labelled "single family":

   a. total nitrogen = 0.09 lbs/ac;

   b. total phosphorus = 0.02 lbs/ac.

4. Calculate total storm load in lbs for 500 acre development using conversion formula in Table 26:

   a. total storm load total nitrogen =
      0.09 lbs/ac x 500 acres = 45 lbs;

b. total storm load total phosphorus =
0.02 lbs/ac x 500 acres = 10 lbs.

5. Compare estimated storm loads of nutrients from developed and undeveloped site:

	total nitrogen(lbs)	total phosphorus(lbs)
Undeveloped	10	1
Developed	45	10
Difference	+35	+9

Conclusions:

Significantly more total nitrogen and phosphorus will be produced from the site and added to the lake from the development. Total nitrogen and phosphorus loading from a one-half inch rainstorm will increase 350 and 900 percent, respectively.

Example 3. Estimation of event mean concentration (EMC) of pollutants from two storms and calculation of average concentration between the two.

As part of a preliminary evaluation of stormwater quality from a 75-acre commercial shopping center, a local planning agency wishes to estimate the event mean concentration of total lead in runoff from a 0.2 and 1.0 inch rainstorm on the site. This range of storm events was chosen as it brackets the majority of rains producing runoff in the agency's region. It is also desired to calculate an average EMC for the two storms. It was estimated that 90 percent of the shopping center is effectively impervious.

Solution:

1. Estimate storm loads of total lead in lbs/acre from the shopping center for 0.2 inch and 1.0 inch rains using Figure 16 and the line labelled "commercial" land use:

   a. 0.20 inch rain will produce: 0.009 lbs/ac total lead;

   b. 1.0 inch rain will produce: 0.027 lbs/ac total lead.

2. Calculate total storm loads in pounds from formula in Table 26:

   a. total storm load for 0.20 inch rain =
   0.009 lbs/acre x 75 acres = 0.68 lbs total lead;

   b. total storm load for 1.0 inch rain =
   0.027 lbs/ac x 75 acres = 2.03 lbs total lead.

3. Estimate runoff from 0.20 inch and 1.0 inch rainstorms at shopping center from Figure 11 given PEI = 90:

a. estimated runoff from 0.20 inch rainstorm = 0.12 inches; runoff.

b. estimated runoff from 1.0 inch rainstorm = 0.73 inches runoff.

4. Convert runoff in inches to cubic feet using conversion formula in Table 26:

a. cubic feet runoff from 0.20 inch rainstorm =
0.12 inches x 75 acres x 3630 = 32,670 cu.ft.;

b. cubic feet runoff from 1.0 inch rainstorm =
0.73 inches x 75 acres x 3630 = 198,743 cu. ft.

5. Calculate estimated EMC for total lead from two rainstorms using formula in Table 26:

a. 0.20 inch rain EMC =

$$\frac{0.68 \text{ lbs}}{32{,}670 \text{ cu.ft.}} \div (6.245 \times 10^{-5}) = 0.33 \text{ mg/L;}$$

b. 1.0 inch rain EMC =

$$\frac{2.03 \text{ lbs}}{198{,}743 \text{ cu.ft.}} \div (6.245 \times 10^{-5}) = 0.16 \text{ mg/L.}$$

6. Calculate estimated average EMC for total lead from two rainstorms using formula in Table 26:

$$\text{AEMC} = \frac{2.71 \text{ lbs}}{231{,}413 \text{ cu.ft.}} \div (6.245 \times 10^{-5}) = 0.19 \text{ mg/L.}$$

Conclusions:

The estimated event mean concentration of total lead was greater for the 0.20 inch rain despite the greater total load produced from the larger storm. For this to have occurred, the percentage increase in runoff volume had to have been greater than the increase in pounds total lead from the 0.2 to 1.0 inch rainstorm. The average estimated EMC of total lead represents the sum of loads divided by storm volumes for the two storms.

Example 4. Estimation of annual suspended solids load and comparison with estimated annual wastewater effluent load from same area.

A planning agency wishes to compare the annual suspended solids loading to receiving waters from urban runoff with secondary wastewater effluent from a 200 acre, one-quarter acre lot, single family development. The following additional information is provided:

- persons per households = 2.61,[17]
- per capita wastewater flow = 65 gallons/day,[18]
- secondary suspended solids effluent load = 30 mg/L.

Solution:

1. Calculate estimated annual suspended solids load from urban runoff from the development. This will require information on average expected yearly rainfall such as is presented in Table 27. This table gives the average number of storms of various sizes anticipated per year in the DRURP study area.

   Estimated annual load (L_T) equals the sum of the individual storm loads (l_i) for each precipitation level (X_i) times the average number of storms of that level expected per year (N_i):

   $$L_T = \sum_{i=1}^{n} l_i N_i.$$

   In this example, precipitation is aggregated into 13 levels (Table 27). Letting Y_1 denote the pollutant load per acre from all the < 0.10 inch events per year, Y_2 the annual load from 0.10-0.19 inches precipitation, up to Y_{13} as the annual load from 2.5 inches, the annual load per acre can be expressed as:

   $$L_T \text{ (lbs/acre)} = Y_1 + Y_2 + Y_3 + \ldots + Y_{13}, \text{ where}$$

   $$Y_i = l_i \; N_i \text{ for any precipitation level } X_i.$$

   The total estimated annual load for the development will then be equal to the annual load per acre multiplied by the total acreage.

   Using data from Table 27 and the line labelled "single family" in Figure 15, calculation of annual total suspended solids from urban runoff load appears in Table 28.

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[17] Denver Regional Council of Governments, "Household and Household Size Forecasts for the Denver Region", DRCOG, July, 1982.

[18] Denver Regional Council of Governments, "Technical Report on Clean Water Plan", DRCOG, August, 1981.

Table 27

AVERAGE EXPECTED YEARLY RAINFALL AT STAPLETON INTERNATIONAL AIRPORT[1]

Rainfall (inches) (X_i)	Average Number Storms Expected per year (N_i)
1) <0.10[2]	20.5
2) 0.10-0.19	6.83
3) 0.20-0.29	3.58
4) 0.30-0.39	1.58
5) 0.40-0.49	0.92
6) 0.50-0.59	1.0
7) 0.60-0.69	0.17
8) 0.70-0.79	0.50
9) 0.80-0.89	0.58
10) 0.90-0.99	0.33
11) 1.00-1.49	1.08
12) 1.50-1.99	0.42
13) 2.00-2.49	0.08

Source: Adams County Planning Department

[1] Based upon data from years 1968 - 1979.
[2] Only storms producing greater than 0.02 inches rainfall were recorded.

Table 28

CALCULATION OF ANNUAL TOTAL SUSPENDED SOLIDS LOAD FROM URBAN RUNOFF

Precipitation in inches (X_i)	Load in lbs/ac(i_i)	Number storms per year (N_i)	Total suspended solids per year in lbs/ac(Y_i)
0.10	1	20.5	$Y = 21$
0.20	7	6.83	$Y = 48$
0.30	15	3.58	$Y = 54$
0.40	23	1.58	$Y = 36$
0.50	32	0.92	$Y = 29$
0.60	42	1.00	$Y = 42$
0.70	53	0.17	$Y = 9$
0.80	64	0.50	$Y = 32$
0.90	75	0.58	$Y = 44$
1.0	88	0.33	$Y = 29$
1.5	155	1.08	$Y = 167$
2.0	231	0.42	$Y = 97$
2.5	314	0.08	$Y = 25$
			$Y_T = 633$ lbs/acre/year

The estimated annual load per acre (L_T) is 633 lbs/acre/year. Multiplying this by 200 acres (development size) gives an estimate of 126,600 lbs/year suspended solids from runoff.

2. Calculate estimated annual suspended solids load from a natural grassland of the same size as the development. This is necessary for a valid comparison of loading from wastewater effluent with urban runoff.

   Annual suspended solids load from the natural grassland is calculated using the same proceedure outlined in the previous step and the line labelled "natural grassland" in Figure 15. Calculations are omitted in order to conserve space and avoid redundancy.

   The estimated annual load per acre (L_T) is 10 lbs/acre/year. Multiplying this by 200 acres (development size) gives an estimate of 2000 lbs/year suspended solids.

3. Estimate annual total suspended solids loading from the development from secondary treated wastewater effluent:

   a. calculate persons in development:

   $$200 \text{ acres} \times \frac{4 \text{ houses}}{\text{acre}} \times \frac{2.61 \text{ persons}}{\text{house}} = \underline{2088 \text{ persons;}}$$

   b. calculate daily wastewater flow in liters:

   $$2088 \text{ persons} \times \frac{65 \text{ gals/person}}{\text{day}} \times \frac{3.785 \text{ liters}}{\text{gal.}} = \underline{513{,}700 \text{ liters/day;}}$$

   c. calculate daily suspended solids load:

   $$\frac{513{,}700 \text{ liters}}{\text{day}} \times \frac{0.03 \text{ gram}}{\text{liter}} \times \frac{1 \text{ pound}}{453.6 \text{ grams}} = \underline{34 \text{ lbs/day;}}$$

   d. calculate annual suspended solids load:

   $$\frac{34 \text{ lbs}}{\text{day}} \times \frac{365 \text{ days}}{\text{year}} = \underline{12{,}410 \text{ lbs/year.}}$$

4. Compare estimated annual total suspended solids loading from urban runoff with that from secondary wastewater effluent from the development:

   - annual load from urban runoff = 126,600 lbs/year;
   - annual load from effluent = 12,410 lbs/year;

- annual load from runoff from natural grassland = 2000 lbs/ year.

Conclusions:

The total estimated annual load of suspended solids from both municipal wastewater and urban runoff from the development is 139,010 pounds. Loading from urban runoff accounted 91 percent of the estimated total load. However, a more objective estimate of suspended solids loading can be made by subtracting the estimated load for the natural grassland of the same size as the development, from the development (urban runoff) load. In this manner, only the load attributable to development can be compared to the wastewater effluent load. If this is done, then the total estimated load of suspended solids becomes 137,010 pounds, but roughly 91 percent of this load is still from urban runoff. Suspended solids loading from the natural grassland is insignificant in this analysis. The majority of the estimated load is from urban runoff.

Summary and Conclusions

Methods and procedures for estimating rainstorm runoff quantity and quality in the DRURP study area for any time period, using a minimum of information and calculations were presented in this section. The figures and methods provided are based upon results and data from the urban runoff monitoring effort (Chapter III).

A graph was presented to estimate rainstorm-runoff quantity based upon land use or PEI. This figure was constructed based on the conclusions that runoff was well related curvilinearly to rainfall within a basin, and that the percent of rainfall occurring as runoff was well related linearly between basins.

Graphs that estimate pollutant loading were constructed based upon the findings that loading varied mainly as a function of runoff quantity, which was found to be dependent upon site PEI, and that loading rates tended to be similar for the same land use. Four practical examples were presented that, hopefully, demonstrated the applicability and usefulness of these graphs for estimating urban runoff quantities, constituent loads, and constituent concentrations.

A more detailed analysis of rainfall-runoff relationships, pollutant loading and model development that includes figures for the remaining constituents monitored (Table 6) is available in a separate technical report from DRCOG.

PREDICTING RECEIVING WATER CHARACTERISTICS

Three methods for predicting receiving-water characteristics were investigated in the DRURP. A regression model relating South Platte River loading to corresponding streamflow conditions was developed. An empirical method of extrapolating the small basin loading relationships to the larger South Platte basin was a second model considered. A third method using a computer-based water-quality model was initiated on two study basins, North Avenue and Cherry Creek. All three of these models will be described.

Regression Model

Streamflow conditions in the South Platte River can be separated into storm-runoff periods and those periods surrounding storms which are referred to as ambient conditions. Relationships between streamflow and the loads of constituents carried by the river can be used for prediction of loads based on discharge if these two variables are sufficiently related to one another. Statistical correlation can provide a relatively simple method of predicting receiving-water characteristics and can be a useful tool for water-quality planning applications.

Both ambient concentrations and ambient loads were regressed individually against monitored instantaneous discharge for use in predicting ambient water-quality characteristics of the South Platte River at 50th Avenue. Least-squares regression analysis produced either linear or curvilinear best-estimate equations. The regression equations which estimate ambient loading based on instantaneous streamflow are presented in Table 29. Streamflow in cubic feet per second (cfs) is entered into the equation to predict a concentration value or instantaneous load directly for the 50th Avenue Station. A load can be estimated from the derived concentration value by multiplying the concentration (in mg/L) by the streamflow (in cfs) and an appropriate conversion factor to produce an instantaneous loading value (in lbs/sec). A daily load can be obtained by multiplying by 86,400 seconds in a day.

Statistical regression techniques can also be used to predict storm loads based on a relationship between storm-runoff volume produced from a rainfall event and the loads carried by this stormflow. Least-squares regression analysis was performed on measured storm loads of selected constituents against corresponding storm volumes from 8 storms monitored in the DRURP at the 50th Avenue Station between April 1980 and September 1981. Curvilinear equations best described the relationships, and these equations are presented in Table 30. Considering the inherent variability in storm-runoff loading, the correlation coefficients and the coefficients of variation indicate that significant relationships do exist and that these equations can be used to predict storm loads based on storm volumes.

Table 29

REGRESSION EQUATIONS DEVELOPED TO ESTIMATE AMBIENT LOADING BASED ON INSTANTANEOUS STREAMFLOW FOR THE SOUTH PLATTE RIVER AT 50TH AVENUE

Equation[1]	n[2]	r[3]	COV[4]
$\text{Load}_{TSS} = 2.27 \times 10^{-5}\ \text{Flow}^{1.8615}$	78	0.95	146
$\text{Load}_{TOC} = 7.30 \times 10^{-4}\ \text{Flow}^{0.9777}$	78	0.88	85
$\text{Conc}_{TN} = 1.14 \times 10^{2}\ \text{Flow}^{-0.5928}$	76	0.89	13
$\text{Conc}_{TP} = 1.98 \times 10^{1}\ \text{Flow}^{-0.5636}$	78	0.87	32
$\text{Load}_{Pb} = -1.69 \times 10^{-1} + 2.83 \times 10^{-3}\ \text{Flow}$	78	0.91	240
$\text{Load}_{Zn} = 9.61 \times 10^{-4}\ \text{Flow}^{0.9220}$	78	0.92	68

Table 30

REGRESSION EQUATIONS DEVELOPED TO ESTIMATE INDIVIDUAL STORM LOADS BASED ON STORM RUNOFF VOLUMES FOR THE SOUTH PLATTE RIVER AT 50TH AVENUE

Equation[1]	n[2]	r[3]	COV[4]
$\text{Load}_{TSS} = 2.191 \times 10^{-7}\ \text{Volume}^{1.7036}$	8	0.87	44.5
$\text{Load}_{TOC} = 1.797 \times 10^{-7}\ \text{Volume}^{1.5480}$	8	0.92	86
$\text{Load}_{TN} = 5.080 \times 10^{-8}\ \text{Volume}^{1.5036}$	8	0.93	67
$\text{Load}_{TP} = 3.602 \times 10^{-6}\ \text{Volume}^{1.1887}$	8	0.88	113
$\text{Load}_{Pb} = 2.656 \times 10^{-5}\ \text{Volume}^{0.9592}$	8	0.70	38
$\text{Load}_{Zn} = 8.000 \times 10^{-10}\ \text{Volume}^{1.5886}$	8	0.91	38

[1] Estimated loads are in pounds, concentrations in mg/L, streamflow in cfs, storm runoff volumes in cubic feet.

[2] n = number of data points; degrees of freedom = n-2.

[3] r = correlation coefficient.
All relationships are significant at the 95% confidence level, except for Pb which is significant at the 90% confidence level.

[4] COV = coefficient of variation, percent.

It must be recognized that all predicted values are only estimates based on the samples collected from the river between April 1980 and September 1981. Associated measures of variability are included in both Tables 29 and 30 for interpretation of the relative accuracy of the predictions.

Estimation of loads using regression techniques can be a useful and simple method for predicting receiving-water characteristics during both ambient conditions and runoff events. These regression equations were used in Chapter IV to predict ambient loads and loads from all storms at 50th Avenue for comparison with sewage treatment plant discharges occurring during the same time period. In addition, the regression equations can serve as a basis for comparison with other (future) water-quality investigations of the South Platte River.

Empirical Model

An empirical model was investigated as another method for predicting receiving-water characteristics. This method used the loading relationships developed from the small urban-runoff basin monitoring data and applied these relationships to the 50th Avenue drainage basin area. Loads derived from these relationships were compared with those actually monitored during a storm event of similar size at the 50th Avenue Station. In addition, loads at 50th Avenue were also estimated using the regression equations previously described for this same size storm event for further comparison of results. In this manner, the relative accuracy of these estimation techniques for predicting receiving-water characteristics can be compared.

The empirical method is described here by way of an example application. The small basin relationships were used in this example to predict loads of TSS, TN, TP, Pb and Zn at 50th Avenue for a 1-inch rainstorm. This amount corresponds to the rainfall which occurred during the storm event of May 28-30, 1981 which was monitored. The land use distribution within the 50th Avenue basin has been previously described in Chapter II. For each lan use type, a unit-area load (in lbs/ac) was obtained from Figures 13 through 17 at the 1-inch rainfall level. This value of the unit-area load for each constituent was multiplied by the area (in acres) of that land use in the 50th Avenue basin to estimate the constituent load (in lbs) contributed by that land use area. The loads produced from the area of each land use were summed for all land use types in the basin to arrive at the total constituent load for the 50th Avenue basin.

Table 31 presents the results of the example application using the empirical method for TSS, TN, TP, Pb and Zn. Also presented in the table are the loads which were measured from monitoring data collected from the South Platte River at 50th Avenue during the May 28-30, 1981 storm. In addition, estimates of storm loads generated using the regression equations

Table 31

COMPARISON OF EMPIRICAL MODEL, REGRESSION MODEL, AND MEASURED LOADS FROM A 1-INCH RAINSTORM AT SOUTH PLATTE RIVER AT 50TH AVENUE[1]

	EMPIRICAL MODEL			REGRESSION MODEL
Land Use Type[2]	Area (acres)	Unit-Area Load (lbs/ac)	Load (lbs)	Load (lbs)
Total Suspended Solids		Measured Load= 4.30×10^6		
Single Family	45,630	87.0	3.97×10^6	
Multi-Family	6,400	21.0	1.34×10^5	
Comm. & Indus.	22,600	39.0	8.81×10^5	
Parks, Vac, Ag	45,370	4.0	1.80×10^5	
Total	120,000		5.17×10^6	4.15×10^6
			(120%)	(97%)
Total Nitrogen		Measured Load= 2.19×10^4		
Single Family	45,630	0.26	1.18×10^4	
Multi-Family	6,400	0.19	1.22×10^3	
Comm. & Indus.	22,600	0.54	1.22×10^4	
Parks, Vac, Ag	45.370	0.030	1.36×10^3	
Total	120,000		2.66×10^4	2.70×10^4
			(121%)	(123%)
Total Phosphorus		Measured Load= 7.86×10^3		
Single Family	45,630	0.055	2.51×10^3	
Multi-Family	6,400	0.040	2.56×10^2	
Comm. & Indus.	22,600	0.062	1.40×10^3	
Parks, Vac, Ag	45,370	0.0040	1.81×10^2	
Total	120,000		4.35×10^3	6.63×10^3
			(55%)	(84%)
Total Lead		Measured Load= 12.2×10^3		
Single Family	45,630	0.012	5.5×10^2	
Multi-Family	6,400	0.012	7.7×10^1	
Comm. & Indus.	22,600	0.027	6.1×10^2	
Parks, Vac, Ag	45,370	0.00005	2.3×10^1	
Total	120,000		12.6×10^3	7.90×10^3
			(103%)	(65%)
Total Zinc		Measured Load= 23.8×10^3		
Single Family	45,630	0.015	6.84×10^2	
Multi-Family	6,400	0.012	7.7×10^1	
Comm. & Indus.	22,600	0.0355	8.02×10^2	
Parks, Vac, Ag	45,370	0.0016	7.3×10^1	
Total	120,000		16.4×10^3	19.0×10^3
			(69%)	(80%)

[1] Measured loads are from May 28-30, 1981 monitoring data.

[2] Abbreviations used for Commercial & Industrial; Parks, Vacant & Agricultural.

derived using a storm volume of 62.2 million cubic feet are included in Table 31.

In order to compare the results of the empirical model and regression-model load-prediction techniques, the estimates from each were divided into the observed (measured) load and expressed in percentage terms. These percentage values are presented in Table 31 below the estimated load in parentheses and represent the percent of the monitored load that was estimated. As can be seen from inspection of these values, results were variable between constituents and models used. However, the differences are not that extreme considering the simplications made in the methods of prediction. All predictions were within 50-150 percent of the observed data, with individual variations as little as 3 percent.

The disadvantage of using the regression model is that an estimate of storm volume is required before a prediction of a storm load can be made. The advantage of the empirical model is that only basin rainfall is required to predict constituent loads.

The extrapolation of the small urban-runoff basin monitoring data to a larger receiving-water system, such as the South Platte River at 50th Avenue, can produce estimates of storm loads which are reasonable.

Simulation Model

Computer-based mathematical models can be used to simulate hydrologic and water-quality processes in natural and man-made water systems. Equations which describe the movement of water and sediment through a drainage basin are solved sequentially at short time intervals. Data on the time history of rainfall, temperature, evaporation, solar radiation, and parameters related to land use patterns, soil characteristics, and man-induced factors (such as sewage discharge and irrigation) are used to simulate the processes which occur in a basin. A continuous history of the quantity and quality of water transported as runoff and groundwater are calculated. Runoff volumes, sediment and nutrient loads, and other water-quality constituent concentrations can be predicted in the receiving waters of the basin. A computer is necessary to handle the large amounts of data involved and the numerous computations made.

The Hydrologic Simulation Program-FORTRAN, known as HSPF, is the model being used in the DRURP. The North Avenue urban runoff monitoring basin (Table 5) and Cherry Creek basin below Cherry Creek Dam (Figure 1) were the study areas chosen for modeling. Progress in modeling these two basins is currently at the hydrologic-calibration phase. Input data was prepared for the meteorologic variables and land-surface parameters, and entered into the data base. The basin parameters were defined and initial calibration runs have been accomplished. Further calibration of hydrology will be required before water-quality calibration can begin. Based on the success of these efforts, a calibrated model for each of the basins will result which will assist in planning efforts.

The goal of applying HSPF to the Cherry Creek basin is to assess the receiving water quality resulting from urban runoff and to evaluate the effects of possible control measures and changes in land use conditions within the basin. Through HSPF calibration procedures and the DRURP data base, the reliability and accuracy of HSPF to represent receiving water quality in a small tributary basin will be determined. Presuming a reasonable degree of success in this effort, the model will be used to assess the effects of urban runoff management practice scenarios for the Cherry Creek basin. The degree to which increased urbanization occurs in the basin will allow predictions of water-quality conditions which may occur in the future. The model can then be applied as a generalized planning tool for water-quality management activities in the DRCOG region.

RADAR PRECIPITATION MAPPING AND TRACKING

One difficulty in predicting urban runoff effects is the proper measurement of the rainfall occurring in an urban area. Rainfall is seldom uniform across the area. This is especially true in an area such as Denver where a major percentage of the annual precipitation occurs as thunderstorms which form in the mountains to the west and move across the region. One area may receive no rainfall from such a storm while another area may record up to 2 inches of rain.

The usual method for gathering data on rainfall is to establish a network of raingages to collect and measure the rainfall. The accuracy of such a network is dependent not only on the gages themselves but also upon the location and number of gages. Relying on too few gages may give a false impression of the amount of rainfall. For example, the official National Weather Service raingage at Stapleton International Airport is the reference station for the Denver area. However, this gage tends to have less rain per year than many other gages in the region.

In order to more accurately describe rainfall, it is usually necessary to develop an elaborate network of gages. The DRURP reviewed the network of gages in place in the Denver region and operated by the National Weather Service, the USGS and the Urban Drainage and Flood Control District (UDFCD). The National Weather Service gages would not provide sufficient data since they provide 24-hour reports only. For brief thunderstorms, 5-minute reports are necessary.

There were 19 such gages operating in the region prior to the DRURP. Additional gages were located in each of the urban runoff monitoring basins described in Chapter II to bring the total number of gages to 35. But even a network of 35 gages cannot fully describe the rainfall patterns for an area as large as the urban area of the Denver region. The budget for the DRURP allowed an additional seven gages to be strategically located to provide additional coverage for the precipitation mapping program (Figure 2).

As can be seen from this discussion, it is a complex and expensive proposition to monitor rainfall patterns using a network of raingages. Unless the network fully covers the area, storms may pass through without being recorded by any gage.

In an attempt to overcome this problem, the DRURP explored the usefulness of weather radar in estimating rainfall patterns. In addition, the radar was used to determine if spatial and temporal precipitation regions exist within the Denver area. The established topography of the Denver region was thought to exert a marked influence on the prevailing weather conditions observed throughout the year. Information on the spatial and temporal distribution of precipation in the Denver region could be used to delineate urban runoff priority control areas based on rainfall. These areas could aid in management decisions to control urban runoff.

To link radar information to rainfall, statistical relationships had to be established. Radar echo returns were recorded on tape and compared to raingage data. The consultant for this effort, Geophysical Research and Development Corporation (GRD), has concluded that "reasonable maps of area precipitation distribution and amount can be produced by synthesizing radar echo returns from precipitation-bearing clouds and a surface rain gage network."[19] The accuracy of radar interpretations is dependent on a number of factors including the availability of ground truth raingage data, the type of storm and the intensity of the storm.

Three types of storms were mapped by GRD from radar images: frontal system rains, thunderstorm rains, and cloud bursts. Not all storms that occurred during the study period were monitored, and ultimately, 25 storms were mapped. Insufficient frontal systems were mapped to allow for individual characterization. Thunderstorm mapping was statistically reliable whenever adequate rainage data were available to calibrate equations. However, cloudburst rainfalls greater than 1.0 inch per hour intensities could not be accurately estimated by radar.

Curvilinear equations were developed between radar intensity and measured rainfall amounts from the network of raingages in the study area. These equations were used to predict rainfall amounts by rainfall "picture" element (pixel) for all storms with enough data. The Denver Region was defined by approximately 1,650 pixels; each pixel is roughly one square mile.

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[19] John F. Henz and Edward W. Pearl, "Radar Precipitation Mapping and Tracking For the Denver Regional Urban Runoff Program," GRD Weather Center, Inc., 1982, (Technical Report available through DRCOG).

Predicted pixel rainfall amounts were analyzed from 12 of 25 rainstorms that had projected data. This sample represented the top 50 percent of storms in size and included thunderstorms and several frontal system events. The probability of a pixel being within the top 10 percent of pixels receiving the most rainfall from a storm was calculated. Those pixels with a probability of at least one in twelve (i.e., were found to have been within the top 10 percent of pixels receiving the most rainfall for at least one storm) were mapped (Figure 20). The areas shown in Figure 20 received the most rainfall from the storms analyzed during the study period. It was found that rainfall amounts were greatest on the average in the eastern portion of the study area.

It is important to recognize that while the spatial pattern of precipitation depicted in Figure 20 was found to exist for the sample of storms studied, this pattern may not be indicative of other years or long- term rainfall in the region. Also if several other large storms that were missed were monitored, the rainfall distribution in Figure 20 may be different. A characteristic of semi-arid climates such as Denver's is large variability in rainfall from year to year. The information in Figure 20 is specific to the two years of study and storms mapped and is not recommended for use in the design of drainage or runoff control programs. The probability of a heavy rainfall-producing storm occurring in one area may be equal to the probability of it occurring in all other areas over a long time period. This analysis demonstrated that spatial variations in rainfall do exist in the Denver region at least over short time periods and that certain areas are more likely to receive greater rainfall from a storm. However, the spatial distribution of rainfall may not be so well defined over the period of many years.

It was concluded that radar rainfall mapping was possible, but that much more research is needed to ensure that radar-prepared maps accurately describe rainfall amounts. Data collection over a period of more than the two years of study as this effort is needed to define long-term spatial distribution of rainfall in the area.

Another element of the radar precipitation mapping involved the identification of preferred thunderstorm tracks. It was concluded such tracks do exist in the Denver region. Figure 21 describes two preferred "thunderstorm alleys" which appear to exist in the Denver area. Over the two seasons of data collection, these "alleys" experienced heavier thunderstorm rainfalls. Most of the northern alley and the eastern portion of the southern alley fall within those areas found to have received heavy rainfall from monitored storms (Figure 20). Comparison of the last two seasons with long term meteorological conditions indicates that the 1980-81 period was typical of historic conditions. If true, these two areas may contribute more urban runoff to regional streams than other areas and should receive priority attention either for nonpoint or urban runoff management. Further information and details of the radar precipitation mapping and thunderstorm track analysis are contained in the previously referenced report by Henz and Pearl which is available through DRCOG.

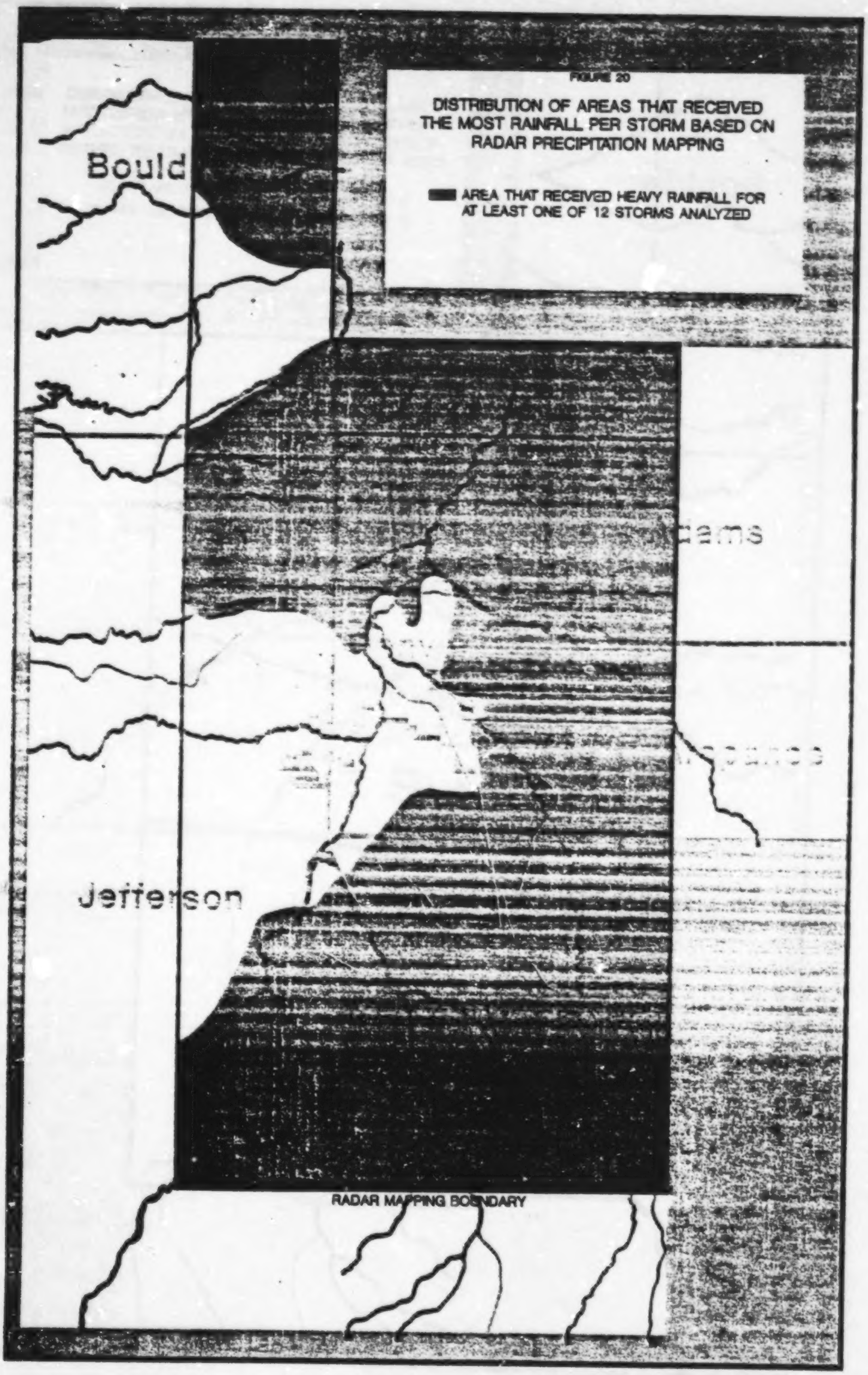

FIGURE 20

DISTRIBUTION OF AREAS THAT RECEIVED THE MOST RAINFALL PER STORM BASED ON RADAR PRECIPITATION MAPPING

▆ AREA THAT RECEIVED HEAVY RAINFALL FOR AT LEAST ONE OF 12 STORMS ANALYZED
Bould
dams
apahoe
Jefferson
RADAR MAPPING BOUNDARY

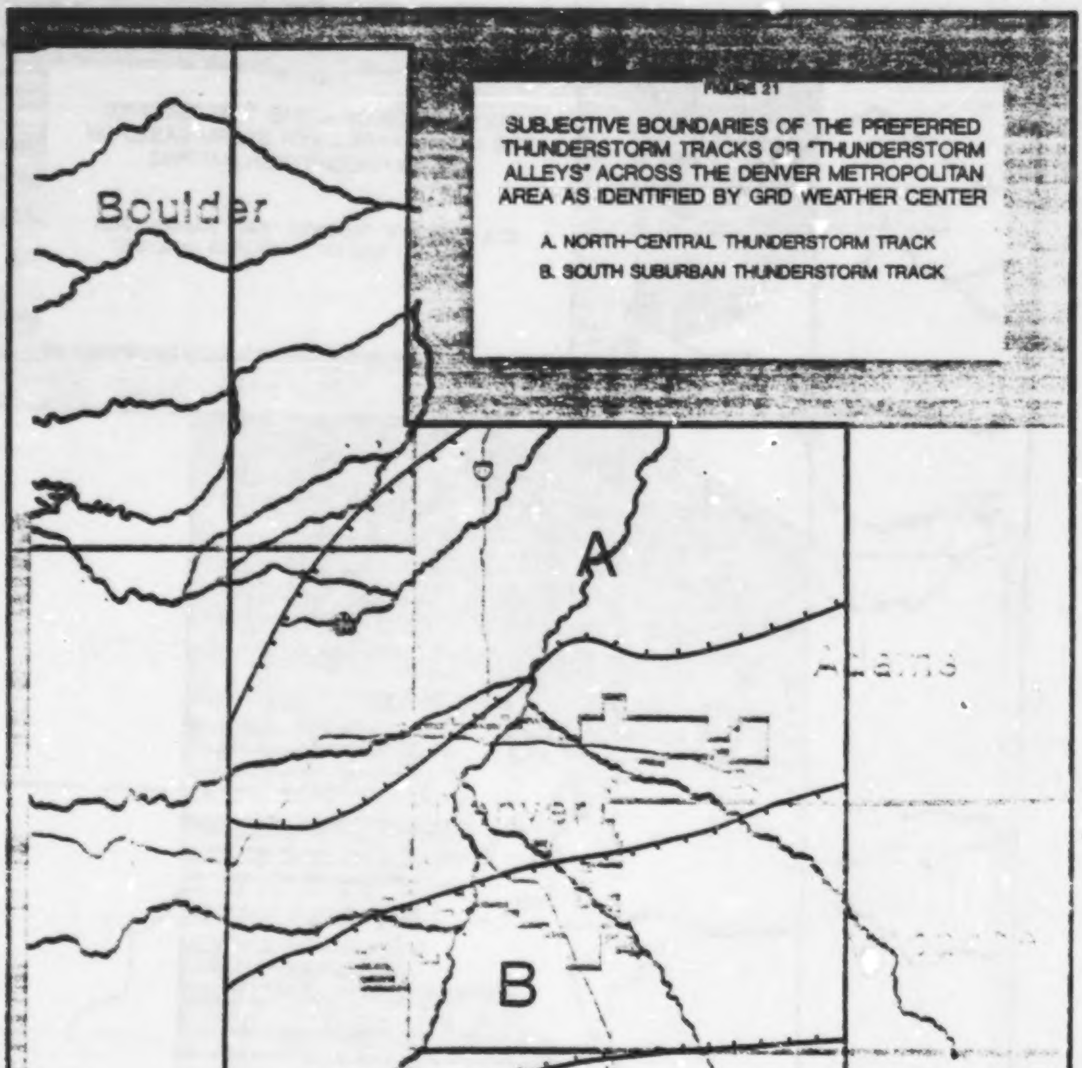
Boulder
A
Adams
Denver
Arapahoe
B
Jefferson
Douglas
RADAR MAPPING BOUNDARY

FIGURE 21

SUBJECTIVE BOUNDARIES OF THE PREFERRED THUNDERSTORM TRACKS OR "THUNDERSTORM ALLEYS" ACROSS THE DENVER METROPOLITAN AREA AS IDENTIFIED BY GRD WEATHER CENTER

A. NORTH-CENTRAL THUNDERSTORM TRACK
B. SOUTH SUBURBAN THUNDERSTORM TRACK

Priority Control of Urban Runoff

An important element of the DRURP involved the identificatin and mapping of areas of high urban runoff formation potential called urban runoff priority control areas. It was originally anticipated that specific problem areas could be defined and these areas would receive special attention in programs designed to control urban runoff in the region. These areas were initially to be defined using information on rainfall derived from the radar precipitation mapping alone with information on land use. However, due to the limitations of the rainfall data discussed in the previous section, and analysis of the effectiveness of the results, an alternate approach was formulated to meet the goals of the task.

This alternate approach abandoned the notion of precisely defining regions of particular runoff pollution potential. As was discussed in the previous section, the likelihood of a specific area receiving substantial rainfall could not be determined to be significantly different throughout the DRURP study area. Any developed area is subject to receive heavy rainfall and consequently produce large quantities of urban runoff. Exclusion of specific areas from a map showing priority areas in the region would be misleading. This is reinforced by the finding that no particular land use type studied produced greater unit-area loads of pollutants (Chapter III) per runoff-inch. It then becomes apparent that defining urban runoff priority control areas by this methodology is of limited utility.

To select an alternate approach, various possibilities and situations for implementation of urban runoff control measures were investigated in regards to their feasibility, effectiveness, acceptability and relative costs. A hiearchy of situations for consideration of control measures was developed and is shown in Figure 22. This hierarchy represents a framework whereby resources may be most efficiently allocated to control urban runoff in an areawide, urban runoff control program. While a regionally effective control program needs to address urban runoff from both developed areas and areas expecting growth, this figure serves as a guide in the decision-making process to direct efforts most efficiently. This is especially important when limited resources are available in a control program.

It can be seen from Figure 22 that control measures should be immediately considered in developing areas. A system of detention ponds, percolation pits and other structures (Chapter VI) can be incorporated into development plans and provide local water quality improvements. The construction of control measures into new developments is presently more feasible than in already developed areas, and the responsibility of such a program would rest more with developers.

It is also recommended that practices for controlling erosion and sedimentation resulting from construction activities be used. Soil loss from large expanses of exposed soil typical during construction activities can be

Highest Priority

Newly Developing Areas:

Construction Activities

Re-developing Areas

Developed Areas:

Existing Structures

Flood Control Projects

Highly Developed Areas

Lowest Priority

FIGURE 22. HIERARCHY OF POSSIBLE SITUATIONS FOR URBAN RUNOFF CONTROL.

substantial. Such erosion may clog drainage structures, impair water quality, and result in the loss of a valuable resource. Best management practices for controlling erosion from construction activities are thoroughly discussed in another DRCOG report entitled Managing Erosion and Sedimentation from Construction Activities.[20]

Implementation of control structures in areas undergoing re-development should receive the next-highest level of consideration. Essentially, areas undergoing re-development contain the same possibilities for implementation of structures as newly developing areas. However, re-development projects are usually limited in scale and restricted in number to older, already developed areas in the region.

Lastly, it is felt that efforts at controlling urban runoff in already developed areas may improve water quality, however, should receive less consideration due to the difficulty and limitations of implementing a program in such areas. Inadequate locations for new structures, costs of installation, and resistance to construction of structures in already established areas may make implementation of an urban runoff control program in developed areas difficult.

Several specific situations were defined and ranked within already developed areas whereby control structures may be more practical and effective. The first of these would be a program to retrofit and enhance existing structures for water quality control. This may entail improvements as easy as altering a flood-control detention pond outlet structure, installing a standpipe, or removing accumulated sediment from a structure.

Next it is felt that water quality enhancement structures could be incorporated into continuing flood-control programs in developed areas. Flood control pond and structure design could be altered to improve runoff quality, along with providing assurance against damage due to runoff volume. This could be accomplished by measures as easy as ensuring that rainfall events smaller than large, design storms are captured by flood control structures.

The final situation in already developed areas where resources for runoff control might be effectively utilized is in highly developed areas, especially if they occur within the basin of a substantial standing water body. It was found in the runoff monitoring effort that the percent of rainfall occurring as runoff was directly related to basin PEI (Chapter III). More runoff will be generated in areas of intense development with high PEI for any rainstorm size. A PEI of at least 24 percent is recommended as a criterion to distinguish between developed areas and highly developed areas. This figure represents an average PEI for high density single family development reported in the previously cited study by Alley and Veenhuis (1979).[21]

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[20] DRCOG, "Managing Erosion and Sedimentation from Construction Activities", April, 1980.

[21] Alley and Veenhuis, "Determination of Basin Characteristics for an Urban Distributed Routing Rainfall-Runoff Model", p.22.

Highly developed areas with PEI greater than 24 percent represent potential problem areas where control structures could be warranted. As was mentioned previously, the feasibility and ease of implementation of structures in such already developed areas is low. Resources would be more effectively utilized in other situations such as is shown in Figure 22 until more research is completed to define acceptable methods for dealing with intensely developed areas.

VI. MANAGING URBAN RUNOFF

Traditionally, stormwater runoff has been considered a nuisance, something to be disposed of as quickly as possible. This attitude toward urban stormwater runoff neglects the problem of receiving water quality deterioration as a result of "flushing" pollutants directly into waterways.

The DRURP results have shown that receiving waters such as the South Platte River are impacted from both point and nonpoint source pollution. Since stream standards consider both point and nonpoint sources of pollution, it may be advantageous to consider the cost effectiveness of attaining stream standards by controlling nonpoint source pollution. For example, if the only consideration made for achieving stream standards is through requiring a point source to undergo advanced wastewater treatment, then nonpoint sources may contribute significant additional pollution and standards may still be violated at certain times. Certainly, relationships should be developed between point and nonpoint source contributions (such as recurrence frequencies, storm event durations, concentrations, and the soluble and suspended fractions of metals) which would identify the role of nonpoint source pollution in establishing stream standards.

An alternative may be to examine the effectiveness of controlling nonpoint source pollution through various structural and nonstructural Best Management Practices (BMPs). An analysis of expected water quality improvements through implementation of BMPs will help determine if extremely costly point source controls will be required.

Best Management Practices (BMPs) can be classified as either structural or nonstructural. Structural controls are usually "effect-oriented" such as detention systems, while nonstructural controls are usually "cause-oriented" such as erosion control ordinances. Because nonpoint source pollution is varied in nature and impact, no individual BMP may fit all situations. The BMPs must be tailored to fit the needs of particular sources and circumstances. The most cost-effective approach to controlling urban stormwater runoff may be a combination of structural and nonstructural control measures.

One element of the DRURP was to investigate several BMPs and methods for implementing BMPs at the local government level. The remainder of this chapter discusses the structural and nonstructural BMPs investigated in the DRURP.

STRUCTURAL CONTROLS

Detention

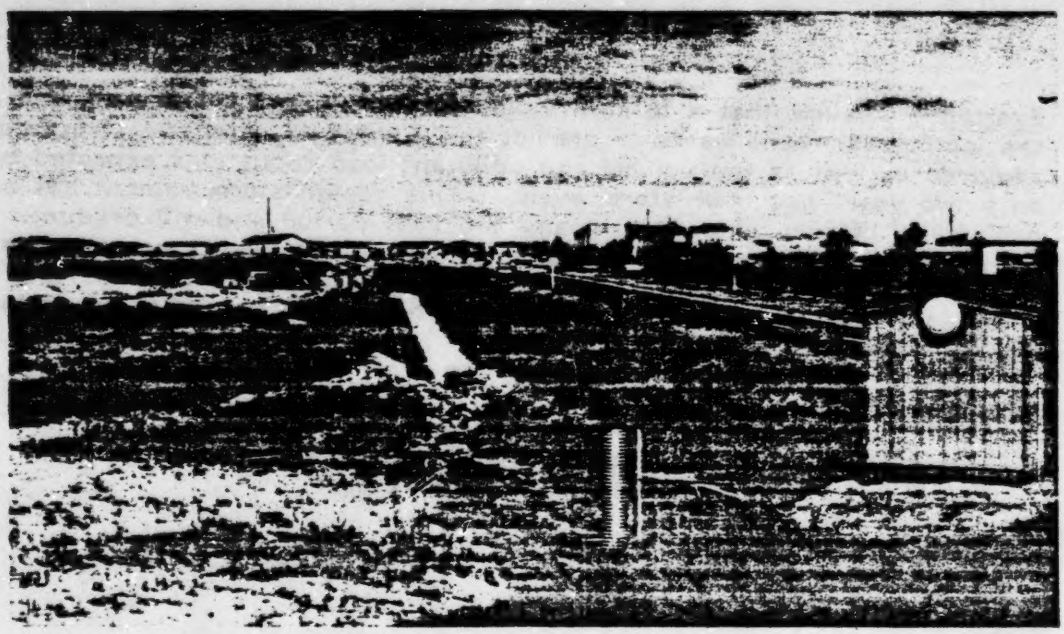
One objective of the investigation of BMPs was to evaluate the pollutant removal efficiency of detention basins. This was accomplished by monitoring storm loads at the North Avenue detention basin, located at the Denver Federal Center.

The detention basin constructed at the Denver Federal Center was originally designed as a dry-type flood control detention system. For the purpose of the DRURP study, the lower end of the system was dammed up to increase detention capacity. The outlet was designed to provide continuous outflow after initial ponding. Cattails and other vegetation were cleared out of the basin but grew back during the sampling period. Capacity (volume) of the structure was approximately 140,000 cubic feet at the point of overflow. Figure 23 shows the detention basin before and after modifications.

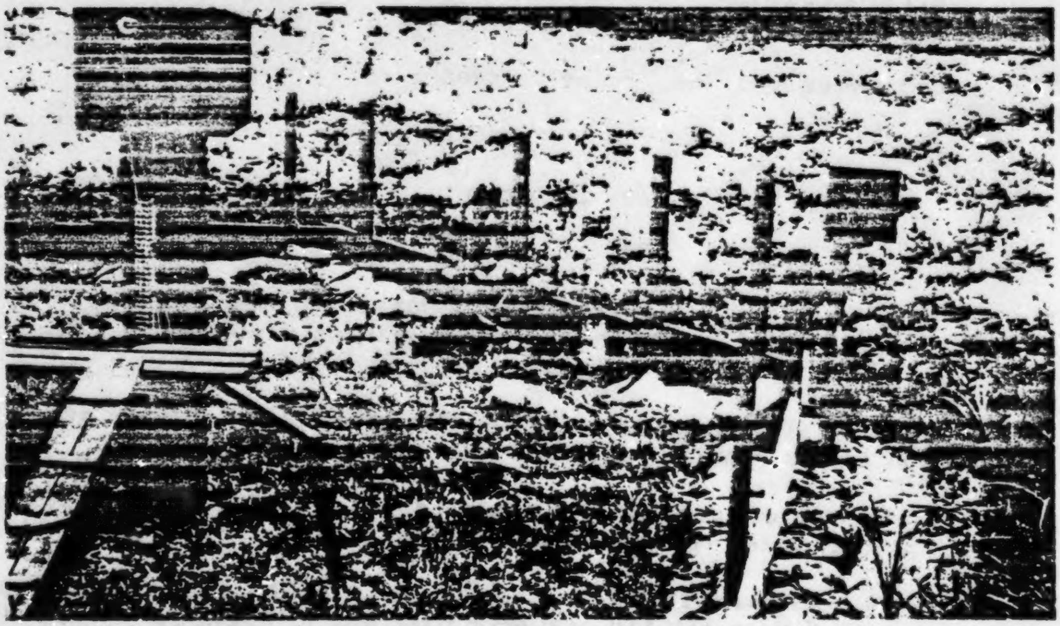
The applicability of this type of retrofit detention system may be possible in the DRURP study area and, therefore, the results can be applied to the entire study area. This type of system can be considered as a BMP for future developments such as single family, multi-family and some commercial development areas as the results did show reductions in storm runoff volume and in runoff loads. Volume reduction through detention is not common for large events; however, the DRURP results did show volume reductions. It is not conclusive if the volume reduction was due to infiltration, evaporation, or accuracy in flow measurements. Retrofitting this type of detention system into existing developed areas could be considered as a BMP, as it appears to be practical and cost effective to slightly modify existing drainage systems to provide for some detention.

Application of Results

If a local government was recommending detention as a BMP for nonpoint source control, the following example illustrates one possible process used to predict the reduction in stormwater volume (cubic feet) and loading (pounds per acre per runoff-inch) from a particular development. This example is based solely on using the same type of detention structure as was monitored at the Denver Federal Center and the same percent reductions in stormwater volume and loading as discussed in Chapter III, URBAN RUNOFF CHARACTERISTICS. The example provided is only an illustration based on the limited data generated by the DRURP study. The results of this example will not be valid for different detention facilities since the performance of each facility depends on its site specific design. Much more local data is needed to develop predictive/design techniques for detention systems which are intended to function for water quality improvement or combination of water quality improvement and flood control.



BEFORE MODIFICATION



AFTER MODIFICATION

FIGURE 23. VIEW OF NORTH AVENUE RETENTION BASIN BEFORE AND AFTER DETENTION MODIFICATION.

Example. Assume that a 75 acre single family development is proposed and the local government wants to predict the number of detention structures required as well as the volume and pollutant load reductions expected based on a two year, one hour storm event. This design storm rainfall has a probability of occurring once in any two year period and will produce approximately 1.0 inch of rain per hour. The water quality constituents of concern include total phosphorus (TP), zinc (Zn), lead (Pb), and total nitrogen (TN). The capacity of each detention structure is assumed to be 140,000 cubic feet (3.21 acre-feet).

The following variables must be known:

1. Land use: Single family residential (23 percent effective imperviousness)
2. Basin Size: 75 acres
3. Rainfall: 1.0 inch
4. Runoff: 0.18 inches (estimated from Rainfall/Runoff nomograph presented in Chapter V)
5. Volume Reduction: 25 percent (based on detention basin analysis presented in Chapter III)
6. Load Reductions:
   - TP 9 percent
   - Pb 14 percent
   - Zn 29 percent
   - TN 9 percent

   (percent reductions are based on the detention basin analysis presented in Chapter III, Table 11.)

The following steps need to be followed to estimate the number of detention basins required and load reductions of pollutants:

1. **Compute stormwater volume produced from 1.0 inch rainstorm, stormwater reduction, and number of basins required:**

   a. **Estimate stormwater volume using 0.18 inches runoff (from Figure 11) and conversion formula in Table 26:**

$$\frac{\underline{0.18 \text{ inches} \times 75 \text{ acres}}}{12} = \underline{1.13 \text{ acre-feet;}}$$

b. Calculate number of detention basins required:

$$\frac{1.13 \text{ acre-feet}}{3.21 \text{ acre-feet}} = 0.4 = \underline{\text{One Basin;}}$$

c. Calculate stormwater reduction:

1.13 acre-feet x 0.25(reduction) = 0.28 acre-feet reduced.

2. Calculate reductions in storm load for the pollutants TP, Pb, Zn, and TN:

   a. Estimate storm loads of these pollutants from a one-inch storm using Figures 13, 14, 16 and 17, the line labelled "Single Family" and conversion factors in Table 26.

	Lbs/acre	Total lbs
TP	0.056	4.2
TN	0.26	19.5
Pb	0.012	0.9
Zn	0.023	1.7

   b. Calculate storm load reductions using percentage reductions given:

	Pre-detention load(lbs)	Percent Reduction	Post-detention load(lbs)
TP	4.2	9	3.8
TN	19.5	9	17.7
Pb	0.9	14	0.7
Zn	1.7	29	1.2

This example illustrates that a detention system similar to the one monitored in the DRURP study can be incorporated into land use planning. It also appears to be an effective BMP for reducing the impact of urban runoff on receiving waters from a small site development. These trends appear promising, but much more field data is needed to develop effective design parameters.

An example of application of detention on a regional basis will be considered next to illustrate the reductions in volume and loading which might be achieved in receiving waters from storm events. The results of the DRURP detention study can be applied to the 50th Avenue basin previously described in Chapter II. This basin has a total area of approximately 120,000 acres. For convenience in this example, the land uses have been broken into the following categories:

Land Use	PEI	Acres
Single Family	22.7	45,630
Multi-Family	41.3	6,400
Commercial[1]	91.2	22,600
Parks, Vacant and Agricultural	0.6	45,370

[1] Includes commercial and industrial acreages

- Following the same steps as outlined before for computing stormwater volumes from a 1.0 inch storm, detention for the entire 50th Avenue basin will produce reductions as presented in the following table:

Table 32

STORMWATER VOLUME REDUCTION (ACRE-FEET) THROUGH DETENTION FOR THE 50TH AVENUE BASIN[1]

Land Use[2]	PEI	Pre-Detention	Post-Detention	Reduction
Single Family	22.7	532.4	399.3	133.1
Multi-Family	41.3	229.3	172.0	57.3
Commercial	91.2	1271.3	953.5	317.8
P, V, and Ag.[3]	0.6	---	---	---

[1] Based upon 25 percent reduction from Chapter III.
[2] Percent effective imperviousnesses denoted on Figure 11 were used.
[3] Negligible runoff produced.

- Following the same steps as previously outlined for computing loads and load reductions as a result of detention, detention applied to the entire 50th Avenue basin will produce significant load reductions. Based on a 1.0 inch rainfall, Table 33 presents loads which will be produced from the storm event and reduced through detention for total phosphorus, lead, zinc, and total nitrogen.

This theoretical application of detention to the entire 50th Avenue basin provides a reasonable example for evaluating detention as an effective BMP. In absolute terms, detention basins can improve receiving water quality as evidenced in Table 33, where total phosphorus is reduced by 389 pounds, lead is reduced by 176 pounds, zinc is reduced 724 pounds and total nitrogen is reduced by 2,324 pounds from one storm event producing 1.0 inch of rain. Whether or not these reductions are significant enough to improve

Table 33

THEORETICAL APPLICATION OF DETENTION TO THE 50TH AVENUE BASIN FOR TOTAL PHOSPHORUS (TP), TOTAL NITROGEN (TN), TOTAL ZINC (ZN) AND TOTAL LEAD (PB) EXPRESSED IN POUNDS[1]

Land Use	Pre-Detention[2]	Post-Detention	Reduction
		TP	
Single Family	2,555	2,325	230
Multi-Family	256	233	23
Commercial	1,379	1,255	124
P,V, and Ag.[3]	136	124	12
Total	4,326	3,937	389
		TN	
Single Family	12,320	11,211	1,109
Multi-Family	1,216	1,107	109
Commercial	12,204	11,106	1,098
P,V, and Ag.[3]	91	83	8
Total	25,831	23,507	2,324
		Zn	
Single Family	1,049	745	304
Multi-Family	77	55	22
Commercial	1,288	914	374
P,V, and Ag.[3]	82	58	24
Total	2,496	1,772	724
		Pb	
Single Family	548	471	77
Multi-Family	77	66	11
Commercial	610	525	85
P,V, and Ag.[3]	23	20	3
Total	1,258	1,082	176

[1] Percentage reductions for pollutants from Chapter III were applied and are based on detention design for water quality enhancement. Flood control detention ponds are not expected to achieve these level of removals.

[2] See Table 31, Chapter V.

[3] Unit area loading for parks, vacant, and agricultural land categories were derived from natural grassland with area loading rates.

receiving water quality on a continuous basis depends largely on whether or not urban runoff has a chronic or acute effect on aquatic life. Also, the beneficial use of the receiving water should be considered when evaluating the potential water quality improvements gained through detention of urban runoff. Based on these considerations, local governments can decide whether or not water quality improvements gained through detention warrant application on a regional basis.

Other Results on Detention

Studies on detention conducted by other NURP projects provided results which were similar in some respects to the DRURP studies, and dissimilar in others. The SEMCOG/Oakland county NURP monitored two residential detention basins. Based on the data collected, reductions in chemical oxygen demand, lead, zinc and copper were found through detention.[22] Reductions in these same constituents were found in the DRURP study. However, SEMCOG reported increases in total organic carbon, total phosphorus, ammonia, and total suspended solids while the DRURP study reported decreases in these same constituents. Both the the SEMCOG NURP and the DRURP reported increases in total Kjeldahl nitrogen and orthophosphate.

The Northern Virginia Planning District Commission (NVPDC) made comparisons between the effectiveness of dry detention ponds and wet detention ponds in terms of pollutant removal.[23] This report prepared by the NVPDC for the Metropolitan Washington Council of Governments concluded that wet ponds were more effective than dry ponds in removing pollutants. This was due in large part to biological and chemical reactions in wet ponds which removed pollutants. Dry ponds were designed for peak shaving purposes and were less effective due to the lack of biological and chemical mechanisms. Conclusions from this report suggested the optimal stormwater detention BMP may be a wet pond with long detention times (greater than 10 hours) with a portion of storage set aside for nonpoint pollution management.

In comparing the DRURP, SEMCOG, and the NVPDC studies on detention, it can be stated that all three found some form of detention to be effective in reducing pollutant loading. However, since the pollutants reduced were not consistent between studies and the actual types of detention were not entirely similar, it is inconclusive at this time as to which type of detention design will be the most effective. At best, detention should be evaluated on a site-specific basis as soils, climate, vegetation, land use and type of structure design will ultimately influence the pollutant removal efficiency.

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[22] Southeast Michigan Council of Governments, "SEMCOG/Oakland County NURP Project: Year Two Annual Report," June, 1981, p. 30.

[23] Northern Virginia Planning District Commission, prepared for the Metropolitan Washington Council of Governments, "NURP Study Quarterly Report, October - December 1981," February, 1982, p. 30.

Most research on water quality improvements through detention have concluded that reductions in certain water quality constituent concentrations are linked to the settleability of particles. As most suspended pollutants have a high affinity for particulates, detention systems should be designed to allow for a maximum settling time of the particulate matter. Laboratory research has supported these conclusions.

In a laboratory experiment conducted by Wipple and Hunter,[24] substantial quantities of pollutants associated with urban runoff were removed after 32 hours of settlement time in an undisturbed, six foot column of water. After 32 hours of settlement, TSS settled out by 70 percent, lead about 60 percent, hydrocarbons 65 percent. Biochemical oxygen demand, copper and nickel settled out more slowly, in the 20 to 50 percent range. Zinc settled out the slowest, from 17 to 36 percent in 32 hours.

Another laboratory study conducted by Randall et al,[25] found removal rates similar to Whipple and Hunter. They found the best reductions were obtained for TSS, lead, and BOD. Average removals of 33 percent or greater were obtained for all major categories of pollutants present in detectable concentrations. The major difference between the two studies conducted by Whipple and Hunter and Randall et al, was the time rate for settling. While Whipple and Hunter's results were obtained over 32 hours, Randall et al, used a settling period of 48 hours.

Both of these laboratory studies demonstrated that pollutants in urban stormwater runoff can be at least partially removed through sedimentation. The most critical factor in removing pollutants is settling time. Given the fact that both studies observed significant pollutant removal at 32 and 48 hours, one would expect that designs for a detention system to detain stormwater runoff for 32-48 hours would be desirable. This implies that ponds with a permanent pool and an overflow riser are probably most effective for water quality enhancement. If maximum pollutant removal is to be achieved through sedimentation or infiltration, then the design of a detention system should maximize settling to the extent possible. Design considerations for maximizing settling times may definitely alter the typical design of a detention system.

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[24] William Whipple, Jr. and Joseph V. Hunter, "Settleablity of Urban Runoff Pollution," Journal of Water Pollution Control Federation, Vol. 53, No. 12, December, 1981, p. 1729.

[25] Clifford W. Randall, Kathy Ellis, Thomas J. Grizzard, and William R. Knocke, "Urban Runoff Pollutant Removal by Sedimentation," proceedings of the Conference on Stormwater Detention Facilities Planning, Design, Operation and Maintenance, sponsored by the Engineering Foundation and the ASCE Urban Water Resources Research Council, Henniker, New Hampshire, published by ASCE, August, 1982.

When considering the use of detention ponds for water quality control, Randall[26] makes the following recommendations:

1. Determine critical pollutant(s);
2. Determine design settling velocity;
3. Calculate required surface area from design settling velocities;
4. Determine infiltration rate of soil;
5. Select pond type: wet or dry;
6. Select outlet system: riser, underdrains, and/or infiltration;
7. Calculate needed riser height and pond depth by design storm considerations;
8. Select pond configurations: long and narrow, two stage or in series; and
9. Determine pond locations and pollutant removal efficiencies needed through use of a watershed-wide computer model.

It should be noted that the pollutant removal efficiencies needed will vary with:

1. Pond location in the watershed;
2. Type of receiving water; and
3. Nature of critical pollutant(s).

In summary, the DRURP study and other studies on detention have demonstrated pollutant removal by detention. It is obvious that the percent removal varies widely and that a very limited data base exists from which to derive significant, meaningful conclusions. Much more local data is needed to determine the extent of pollutant removal by detention for the DRURP study area. However, we do know that if detention is to be used for the dual purpose of flood control and water quality improvement, then design becomes an important factor which must be carefully studied.

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[26] Clifford W. Randall, "Stormwater Detention Ponds for Water Quality Control," proceedings of the Conference on Stormwater Detention Facilities Planning, Design, Operation and Maintenance, sponsored by the Engineering Foundation and the ASCE Urban Water Resources Research Council, Henniker, New Hampshire, published by ASCE, August, 1982.

Cost Estimates for Detention

Cost estimates for detention basins appear to be considerable in terms of capital investment. However, this investment is a one-time investment cost and can be included as part of the initial development costs. Maintenance costs should also be considered in a detention system as trapped sediment should be removed as required.

Since detention systems vary in size, the cost estimate presented here is based on the cost per acre of drainage area. Table 34 presents these costs in 1982 dollars for design, materials, construction and annual maintenance:[27]

Table 34

COST ESTIMATE FOR CONSTRUCTING A DETENTION BASIN BASED ON PER ACRE OF DRAINAGE AREA

Design	Materials	Construction
$10-25/acre of drainage area	$20-30/linear ft. for corrugated steel pipe	$100-300/acre of drainage area

Total Costs	Annual Operation and Maintenance
Approximately $200-400/acre of drainage area	$50-100/acre of drainage area/year

Applying this total cost figure of about $400 per acre to the previous example of a 75 acre single family development, the cost for a detention system would be approximately $30,000. If a density of 6 houses per acre is assumed, the cost per house would be $67, a relatively inexpensive cost compared to the benefit. However, the $30,000 should be paid by the developer as part of all the utility requirements for a subdivision.

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[27] Wright-McLaughlin Engineers, prepared for the Denver Regional Council of Governments, "Cost of Erosion Control Measures," Supplemental Report, May, 1982.

Percolation Pits

Percolation pits are another BMP which can be considered for controlling stormwater runoff in certain areas. In principle, they function similar to detention basins in that stormwater is routed to the pit where it is detained. Instead of passing the stormwater on through an outlet to a surface-water drainage system, it is allowed to filter into the groundwater through a substrate material. Figure 24 shows a typical percolation pit design.

An additional consideration of the DRURP BMP program was to investigate the applicability of percolation pits as another alternative measure for stormwater management. The Adams County Planning Department cooperated in the program by investigating percolation pits as a BMP control measure. The county has an abundance of sandy and gravely subsoils which are conducive to draining stormwater runoff rather quickly. The idea of percolating stormwater into subsoils provides an additional benefit of groundwater recharge as well as reducing the direct impact of stormwater on receiving waters.

The report on percolation pits as prepared by the Adams County Planning Department was compiled into a convenient brochure.[28] The brochure indicates that percolation pits should be considered as a BMP for stormwater control in areas which have subsoils conducive to high percolation rates.

In summary, the brochure provides the following information on the use of percolation pits in Adams County, Colorado:

- Design. Information is presented on optimum pit design which reduces maintenance and pit size;
- Drainage regulations. The concept of percolation pits for stormwater control fits into the existing drainage regulations. The use of percolation pits also reduces the space requirements for detention basins and virtually eliminates stormwater pollutants from frequent, small rainstorms;
- Limitations. Percolation pits do have some limitations in that they shouldn't be considered in areas where toxic substances can be transmitted to the groundwater, where the groundwater table is shallow, where nearby basements could easily be flooded, where soil percolation rates are less than 0.6 inches/hour and where the slope is greater than 10 percent;

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[28] Adams County Planning Department, "Percolation Pits: Their Design, Construction, Use, and Maintenance for Stormwater Disposal, Groundwater Recharge, and Surface Water Quality Protection in Adams County, Colorado," 1982.

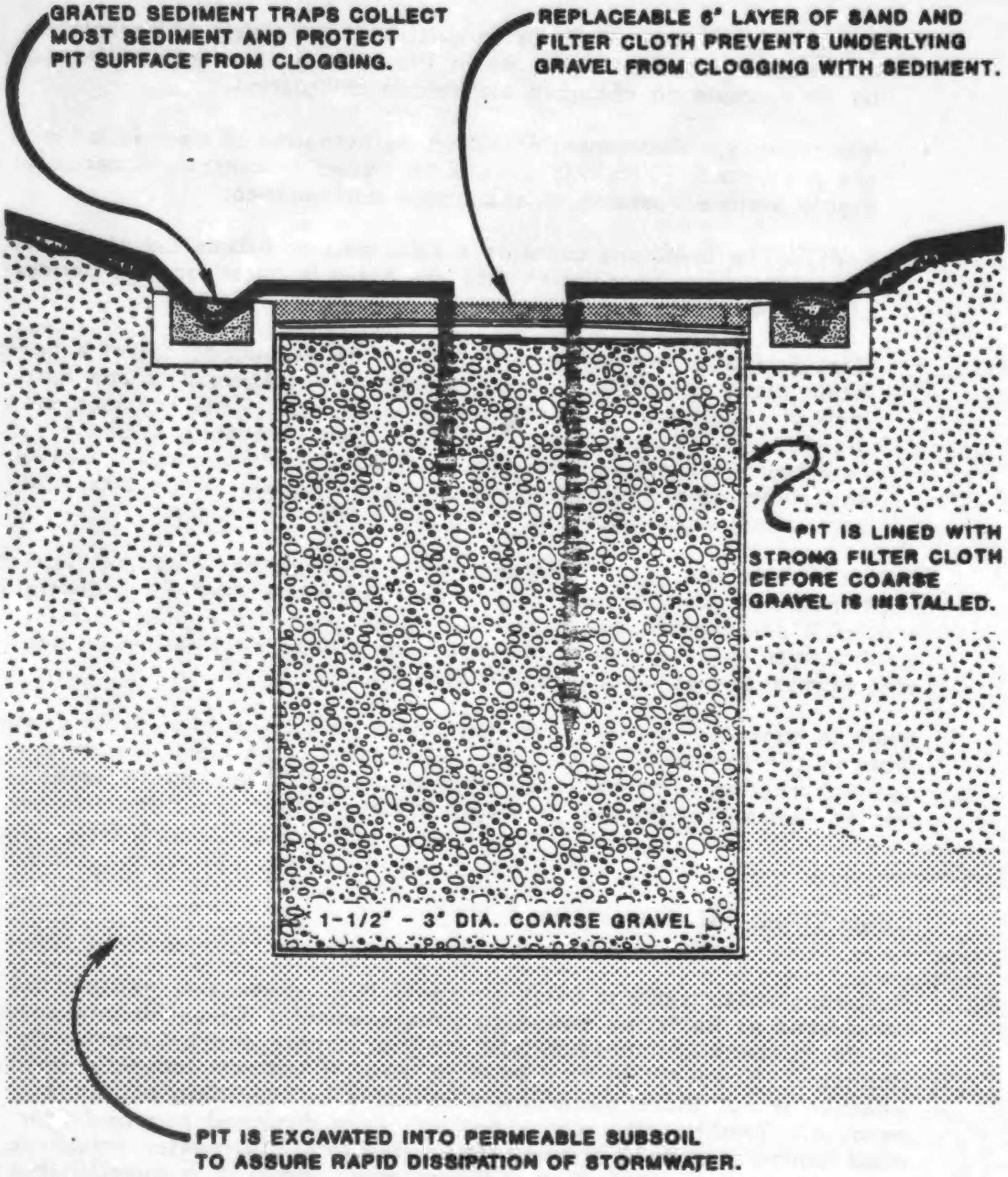
GRATED SEDIMENT TRAPS COLLECT MOST SEDIMENT AND PROTECT PIT SURFACE FROM CLOGGING.
REPLACEABLE 6" LAYER OF SAND AND FILTER CLOTH PREVENTS UNDERLYING GRAVEL FROM CLOGGING WITH SEDIMENT.
PIT IS LINED WITH STRONG FILTER CLOTH BEFORE COARSE GRAVEL IS INSTALLED.
1-1/2" - 3" DIA. COARSE GRAVEL
PIT IS EXCAVATED INTO PERMEABLE SUBSOIL TO ASSURE RAPID DISSIPATION OF STORMWATER.

FIGURE 24. PERCOLATION PIT DESIGN SCHEMATIC.

- **Design standards.** **Methods to calculate the sizing of percolation pits based on impervious area in the basin is presented followed by an example on required pit volume calculations;**

- Maintenance. Recommendations on maintenance of percolation pits are presented. The pits should be placed in central, accessible, highly visible locations to encourage maintenance;

- Soils. The brochure contains a soils map of Adams County which indicates where percolation pits are feasible based on soil permeability; and

- Cost Estimates for Percolation Pits. The estimated cost of a percolation pit is described. A pit designed to accommodate one-half inch of runoff per impervious acre is $5,600. This is based on a pit size of 15 square feet by 20 feet deep, assuming a 20 inch/hour infiltration rate and 1 acre of imperviousness. Gravel and filter cloth would cost approximately $4,600 of the total and excavation would cost approximately 1,000.[29]

In conclusion, the report prepared by Adams County Planning Department indicates that percolation pits are a practical BMP for stormwater control if soil percolation rates are greater than 0.6 inches/hour. Applicability to a particular site will also depend on whether or not other limitations as discussed are present.

Prior to considering the use of percolation pits, the total groundwater table in the watershed should be investigated. This will insure against creating a rising water table which would surface in basements, damage foundations or degrade pavements.

Other Structural Controls

Numerous other methods exist for controlling stormwater and can be considered as BMPs for managing urban runoff. These include porous pavement, parking lot detention, rooftop storage and underground drainage. However, at this point in time, it appears inconclusive whether or not these methods are effective in providing pollutant removal. Traditionally, these methods were designed purposely for flood control and peak shaving where the total stormwater volume is slowed down and released at a slower rate. While it is questionable as to the pollutant removal efficiency of these methods, they do have a potential role in land use planning for controlling urban runoff.

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[29] Jon Colt, Presentation to the DRURP Technical Advisory Committee, March 1982.

Where stormwater runoff poses a threat to a public drinking water supply, it may be reasonable to protect the water supply at any cost. A case in point is the City of Englewood, where the City's water supply, McLellan Reservoir, may receive stormwater runoff generated from new developments upstream of the reservoir. Several different methods of stormwater treatment were evaluated by the City of Englewood as a part of the DRURP. Costs and pollutant removal efficiencies for each treatment method were investigated. The recommended control alternative was to construct a sedimentation basin upstream of the reservoir which discharged stormwater to a rapid infiltration pit adjacent to the reservoir. This combined treatment system provided adequate pollutant removal and will cost approximately $1,000,000.[30]

NONSTRUCTURAL CONTROLS

Nonstructural controls for managing urban runoff in some cases may be more effective and less costly than structural controls. Erosion control is a good example where sediment generated from construction activity can be significant[31] but control of erosion may be relatively simple and inexpensive.[32]

The DRURP did not attempt to measure the effectiveness of any nonstructural control measures but intended to rely on other NURPs for these results. The three main nonstructural BMPs to be considered in this discussion are street sweeping, erosion control, and maintenance of drainage facilities. These three measures were chosen because street sweeping was originally thought to be a very effective BMP, erosion control is an area where DRCOG has done previous work, and maintenance can improve the efficiency of an existing drainage system.

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[30] Black & Veatch Consulting Engineers, prepared for the City of Englewood, Colorado, "Report on McLellan Reservoir Water Quality," Chapter 10, "Evaluation of Stormwater Treatment Alternatives for McLellan Reservoir," 1982.

[31] Denver Regional Council of Governments, "Managing Erosion and Sedimentation from Construction Activities, Interim Best Management Practices," April, 1982, p. 9.

[32] Wright-McLaughlin Engineers, "Cost of Erosion Control Measures," May, 1982.

Street Sweeping

Preliminary results of the Nationwide Urban Runoff Program indicate that only one of the six street sweeping projects reported that loads were reduced as a result of increased street sweeping, and that one noted an improvement in receiving water quality.[33] Another noted some load reductions, but this was not reflected in their water quality data, any effect being masked by variability in the data. Three other projects could find no water quality benefit from increased street sweeping due, again, to high data variability.

While these results are preliminary and may change as more data is collected and analyzed, street sweeping does not appear to be as effective as originally anticipated. Additionally, annual street cleaning costs tend to increase proportionally as a function of the cleaning efficiency. The increase in cost to remove a marginal unit of pollutant from the street increases steeply with increased street cleaning, and a street cleaning frequency of three times per week would provide the optimum reduction of street surface contaminants.[34] It appears that the only benefit derived from street sweeping is the visual aesthetic improvement from removing accumulated sediment and trash.

Erosion Control

Erosion control appears to be an effective BMP for controlling nonpoint source pollution in the Denver region. Sediment production from construction activities can be controlled through various temporary and permanent measures. Costs for erosion control measures range from less than one dollar per linear foot for design, materials and construction for some temporary measures to several hundred dollars per cubic yard for design, materials and construction for many of the permanent measures.[35]

Planning for erosion control is an important element in an erosion control program. Costs for developing an erosion control plan as a part of the initial planning process for a proposed development are small and will not add significantly to the total project planning costs. Much of the information necessary for erosion control planning will already be available as a part of the information base for the project. Costs for developing erosion control plans range from $85.00 per acre for a 13 acre site to $7.50 per acre for a 350 acre site.[26]

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[33] Water Planning Division, U.S. Environmental Protection Agency, "Preliminary Results of the Nationwide Urban Runoff Program," Vol 1, March 1982, p. 5-60.

[34] Robert Pitt and Gary Shawley, with assistance from Woodward Clyde Consultants, "San Francisco Bay Area National Urban Runoff Project, A Demonstration of Non-Foint Source Pollution Management on Castro Valley Creek," Draft, June, 1981, pp. 1-7, 1-8.

[35] Wright-McLaughlin Engineers, "Cost of Erosion Control Measures," May, 1982.

The key to a successful erosion control program is local government implementation. This includes adoption of an ordinance, reviewing plans and site inspections. Estimates place the initial cost to local governments for implementing an erosion control program at about $3000 to $8000. These figures should not be viewed as strictly out-of-pocket costs because the bulk of the money is attributable to staff time, which is already budgeted. The annual cost to review and inspect from 80 - 100 projects having grading permits has been estimated at $10,000 to $12,500. The majority of this amount should be recovered in permit application fees and maintenance cost savings. Costs are summarized in Table 35.

Table 35

SUMMARY OF COSTS FOR EROSION CONTROL PROGRAM IMPLEMENTATION.[27]

Description	Costs	Man Hours
Ordinance Adoption	$ 3,000 - $ 8,000	
Plan Review		
Building Permits	$ 15 - $ 230	(1-18.5 man hours)
PUDs & Subdivisions	$ 105 - $ 465	(5.5-23 man hours)
Inspections	$ 66 - $ 290	(4-18 man hours)
Estimated Annual Cost (80 - 100 permits)	$10,000 - $12,500	

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[26] Wright-McLaughlin Engineers, prepared for the Denver Regional Council of Governments, "Factors Affecting the Cost of Erosion Control Planning," Technical Memorandum, June, 1982.

[27] Wright-McLaughlin Engineers, prepared for the Denver Regional Council of Governments, "Costs of Local Governments for Implementation of Erosion Control Programs," Technical Memorandum, July, 1982, p. 22.

Maintenance

Often, one of the most neglected nonstructural controls is maintenance of detention and drainage systems. Effective maintenance operations can reduce repair costs, flooding, lengthen the life span of facilities, improve water quality and provide aesthetic benefits.

If not planned for, drainage system maintenance may be abandoned due to the relatively high costs. For example, the costs for the City of Littleton to implement a maintenance program are estimated at $100,000 per year including all administrative, inspection, and maintenance costs.[38] It is recommended that a complete survey of existing drainage facilities be conducted to identify the number of facilities and to assess the required maintenance to bring all facilities up to a good operational level.

MODEL IMPLEMENTATION PROGRAM (MIP)

The objective of the Model Implementation Program (MIP) was to test the feasibility of implementing BMPs at the local government level. To meet this objective, DRCOG encouraged local governments to participate in the MIP to assist in evaluating the urban runoff problem and recommend certain control measures. It was anticipated that the nonpoint source control recommendations developed by the participating local governments would be incorporated into existing local regulations.

During the three year DRURP, three local governments agreed to participate in the MIP. Adams County, the City of Littleton, and the City of Englewood all expressed an interest in the program and a desire to control certain aspects of urban runoff.

Adams County

Adams County has participated in the program for the entire three year duration of the project. Due to the fact that the county is downstream of the urbanized metropolitan area, it receives the largest collective impact from urban runoff in the South Platte river. County officials decided that involvement in the DRURP BMP/MIP would be beneficial as information collected for controlling urban runoff at the local level would be a model program which could be applied regionally. As a result, the effects of urban runoff within the county could be reduced.

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[38] Simons, Li & Associates, Inc., prepared for the City of Littleton, Colorado, "Annual Maintenance Program for Storm Water Drainage Facilities," Final Report, June, 1982, p. 25.

Adams County investigated a number of problems related to urban runoff. The following summary highlights the findings from Adams County:

Establish Safe Recreational Use Guidelines

Information indicated that several of the county's waterways are intermittently acceptable for recreation. It was hoped that a simple relationship between fecal coliform bacteria and suspended sediment loading or turbidity could be developed. These relationships would then be used to develop threshold criteria for local recreationists to observe prior to using the waterways. Due to a lack of coordinated, comprehensive data, the relationships could not be developed. This precluded any determination of recreational use guidelines with respect to urban runoff and acceptable water quality.

Determination of Local Annual Sediment Loss Design Limits

This study was originally designed to define the relationships between sediment loading, fecal coliform bacteria, storm events, and known land-disturbing activities from available local, regional, and comparative national data. One goal among the objectives of this study was to derive appropriate uniform erosion-control design criteria for use by local land developers that was consistent with local water quality goals and could be readily incorporated into the county's Zoning Regulations, Subdivision Regulations, and their field enforcement. Initiation of new State distinctions between urban-derived and rural-derived fecal coliform bacteria prevented establishment of fecal coliform relationships. Available sediment loss data compiled by the U.S.D.A. Experiment Station and other basin studies in the U.S. assisted in narrowing the range of design criteria appropriate for regional use. An exact match of DRCOG - USGS small-basin sediment loss monitoring data and "Universal Soil Loss Equation" predictive data was not achieved, however, because of the use of a suspected overly high regional rainfall factor by the State Soil Conservation Service. In response, the county incorporated the erosion control design criteria defined by the Soil Conservation Service into its regulations and enforcement, which are based on annual average soil loss limits of 1,2,3, or 5 tons per acre per year, depending on soil type. In addition the county is promoting greater information exchange between DRCOG and the Colorado Soil Conservation Service to determine if the regional rainfall factors should be altered to more closely approximate the small basin monitoring data.

Percolation Pit Brochure

As described earlier in this chapter, the county prepared a brochure on the design and applicability of percolation pits for controlling stormwater runoff. A great deal of coordination between the county planning department and engineering department occurred in preparing the brochure and in recommending percolation pits for stormwater control.

Field Inspection of Existing Stormwater Detention Facilities

The intent of this study was to conduct field inspections of all privately-constructed detention systems in the county to evaluate their present and historical ability to trap sediment. This would lead to refining private development standards and their enforcement by the county.

A total of 48 private developers' plans for detention facilities were located within the files of the County Engineering Department. The plans had been submitted between 1976 and 1981, and building permits had been issued. Of the 48 developments inspected, only about half of the developments either had been constructed or were far enough along in the construction to enable definite observations to be made. Six of the constructed detention systems were found to provide good detention and sediment removal. Four other systems were borderline in terms of detention sedimentation efficiency. The remainder of the partially- or fully-constructed developments possessed either partial or insufficient detention, contrary to the county-required original design specifications. This was primarily due to insufficient coordination between the County Building Department and Engineering Department regarding timely inspections of drainage facilities during the developments' latter phases of construction. The results of this lack of coordination became apparent only upon conducting the field inspection of detention facilities. As a result, uniform procedures are being developed which will "plug the holes" in the County's drainage enforcement process, and will incorporate erosion control enforcement simultaneously.

Erosion and Sediment Control Regulations

As a result of the construction activity occurring in Adams County, the county proposed an erosion and sediment control regulation in the county Subdivision Review Regulations. After pursuing adoption of this regulation for three years, the Board of County Commissioners adopted the regulations in June 1982. The regulations outline the minimum design standards for adequate erosion and sedimentation control during and after construction activities for subdivisions, planned unit developments, or other proposed construction.

Erosion Control Plan Review Procedures

The county is in the process of developing new procedures for reviewing and enforcing the new erosion control plans. The review will be a coordinated effort and cover drainage and erosion control requirements by Planning, Building and Engineering Departments.

Erosion Control Manual

The county is preparing a manual on erosion control techniques which developers can use in preparing and implementing erosion control plans. This manual outlines specific control measures, costs of the measures and was developed as a result of the recently adopted Erosion and Sedimentation Control Regulations. This manual also discusses other institutional alternatives for controlling erosion at the local level.

City of Littleton

The City of Littleton participated in the BMP/MIP during the third year of the DRURP. The city frequently experienced problems associated with urban runoff, and construction activities upstream of developed areas often produced sediment which clogged the existing drainage system. The city has a relatively weak drainage ordinance and, as a result, the best solution to stormwater runoff was to convey it to the South Platte River as quickly as possible.

As their part of the DRURP BMP/MIP, the city studied three areas of improvement: drainage, erosion control ordinance, and a stormwater drainage maintenance program.

The drainage program involved preparing a manual on improving stormwater detention methods within the city limits. Recommended applications of detention methods and improvements in receiving water quality as a result of improved detention methods were presented. As a follow up to improved detention, a stormwater drainage system maintenance program was prepared. The maintenance program detailed methods to keep drainage systems operating properly through planned maintenance and provided an estimate of annual costs ($150,000-$200,000) to the City for implementing a maintenance program.[39]

An erosion control ordinance was also prepared with the intent of preventing clogged drainage systems due to construction activities upstream. Annual costs to the city for implementing an erosion control program were estimated at $5,000 to $10,000.[40]

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[39] Ibid.
[40] Ibid.

City of Englewood

The City of Englewood relies upon water stored in McLellan Reservoir as a source of drinking water. Presently, the watershed tributary to the reservoir is undeveloped, but the city is concerned that the reservoir could become polluted as a result of increased stormwater runoff from development within the watershed. It is the intent of the City to maintain the present quality of water in the reservoir even after the entire watershed becomes fully developed. The present undeveloped watershed contains 6000 acres of rolling range land with grassland vegetation. Once the watershed is developed, the increased impervious area will increase stormwater runoff by about 350 percent, or 1500 acre-feet per year from storm events of one inch or less. The initial reaction by the City was to require developers to install a pipe which would divert all runoff from storm events of one inch or less around the reservoir to the South Platte River The estimated expense for installing such a pipe appeared to be cost prohibitive.

Due to this unique problem, the City of Englewood became involved in the BMP/MIP during the third year of the DRURP for the purpose of investigating alternative stormwater treatment methods. It was anticipated that an alternative to diverting the stormwater could be discovered, whereby the stormwater could be treated and released into the reservoir. Hopefully, a treatment method would be less costly and provide the City with additional water while not degrading the quality of water in the reservoir.

Treatment methods which were evaluated included: 1) a wetlands system, 2) infiltration pits, 3) mechanical treatment such as a wastewater treatment plant, 4) a series of detention ponds within the watershed, and 4) an innovative treatment method such as flow balancing tanks within the reservoir. Each method was evaluated in terms of feasibility, cost, maintenance, and pollutant removal.

After each method was evaluated, a recommendation was made to construct a rapid infiltration basin next to the reservoir. Upstream of the infiltration basin, a large sedimentation basin would capture the initial stormwater runoff and release it to the infiltration basin at a much slower rate. This combined system of a sedimentation basin followed by an infiltration basin not only provided adequate pollutant removal but cost approximately $1,000,000. This amount is significantly less than the cost of diverting the stormwater to the river via a pipeline.[41]

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[41] Black & Veatch Consulting Engineers, prepared for the City of Englewood, Colorado, "Report on McLellan Reservoir Water Quality," Chapter 10, "Evaluation of Stormwater Treatment alternatives for McLellan Reservoir," 1982.

Other Local Government Contacts

During the three year DRURP, many local governments were contacted and encouraged to participate in the BMP/MIP. Contacts were made with the City and County of Denver, City of Aurora, City of Westminster, City of Boulder, Douglas County, and Jefferson County. These local governments chose not to participate, due to various reasons. Mainly, a lack of staff and insufficient funds for the in-kind match were predominant reasons for not participating. Other reasons included fear of becoming involved in a federally-funded project, costs to implement the results even though they were not required to implement them, and one jurisdiction felt that stormwater was not a water quality problem.

VII. CONCLUSIONS AND RECOMMENDATIONS

The three year DRURP effort has been an attempt to quantify urban runoff effects on water quality in the Denver area. It should be apparent from the previous chapters that much has been learned about urban runoff. This chapter pulls these findings together, evaluates the methods available to manage urban runoff and suggests areas for additional study or implementation.

URBAN RUNOFF AS A PROBLEM

Traditionally, the major problem with urban runoff has been flooding. As mentioned in Chapter III, urban development increases the amount of runoff which enters the surface drainage system. Development, due to an increase in impervious area within a basin, may increase runoff to a point where existing drainage networks are inadequate and flooding results. However, urban areas have been responding to this problem by developing better drainage systems through their own resources and those of entities such as the Urban Drainage and Flood Control District (UDFCD) in the Denver region.

However, quantity is not the only concern with urban runoff. This study has shown that urban runoff is also a significant source of some water pollutants. In both the small basins and the instream sampling, the concentrations of some pollutants exceeded the adopted stream standards.

The most obvious pollutant connected with urban runoff was total suspended solids. During months of heavy rainfall, urban runoff contributed up to 90 percent of the total suspended solids load to the South Platte. All land uses contributed to this load, with single family areas having the highest unit-area loads. This was true whether or not there were major land disturbances causing erosion.

Connected with suspended particles are many metals. While some of these metals such as lead and zinc were found in concentrations which may be harmful to fish or humans, their association with suspended material may allow control through sedimentation processes.

Nutrients in urban runoff were also high, however, concentrations of most nutrients were higher in wastewater effluent. The level of nitrogen and phosphorus in urban runoff can contribute to eutrophication problems in downstream lakes and reservoirs.

On the positive side, the amounts of nitrate and nitrite contributed to surface waters by urban runoff were not high. The impact on water supplies should be minimal.

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One major finding is the significant volume of pollutants contributed to the South Platte by non-storm urban drainage. The water running off of lawns, down gutters and into the area's drainage network is greatly adding to the load of pollutants in the river. In the past this has not been considered a major factor in water pollution. However, it may be necessary to consider this source if water quality goals are going to be achieved.

Another major conclusion of the DRURP is that storm runoff quality varies depending on land use. Different land uses contributed different amounts of pollutants depending upon their extent of effective impervious surface. The amount of runoff generated on an area also depended on percent of effectively impervious area. The higher the PEI, the more runoff.

These relationships were sound enough that runoff quality could be predicted from land use characteristics. Simple, desk-top models were developed and procedures detailed which allow for an assessment of the impacts of development on water quality. Also, these relationships allowed for calibration of the simulation model, HSPF. Both of these models can be used by planners to predict river system changes due to point and nonpoint controls.

While more data than ever before was gathered about urban runoff during the DRURP, these findings are still based on a limited data base. Continued monitoring and data analysis are necessary to confirm and expand the findings of this study.

MANAGING URBAN RUNOFF QUALITY

Chapter VI described the various control measures available to modify the quality of urban runoff. The issue for an area such as the Denver region is whether it is cost effective and efficient to develop an urban runoff, quality-control program. Such a program would have two objectives: (1) achieve water quality which will maximize the beneficial uses of the region's water system, and (2) reduce the need for advanced treatment at wastewater treatment plants.

To accomplish these objectives, the efficiency of control measures must be determined. The DRURP evaluated two measures and found both to provide benefits. The detention basin studied was shown to reduce loads and concentrations of a number of pollutants. A review of literature regarding detention basins in other regions showed simular benefits for certain, properly designed basins. Likewise, percolation pits were shown to be an effective way to deal with runoff from frequent, smaller volume storms which constitute most of the regional urban runoff quality problem.

While the DRURP did not test other control methods, other NURP projects did. It appears that many proposed techniques such as street sweeping and catch basin maintenance have a very limited effect on water quality.

Based on the costs of these programs, they should not be expected to achieve water quality goals alone. Where carried out for other benefits (aesthetics, erosion control, or flood control), they may assist in controlling runoff quality.

While it was not possible to define urban runoff priority control areas within the Denver area due to the limited rainstorm data available, a hierarchy of situations where resources would be most efficiently used for runoff control was formulated. Based upon the amount of construction activity, feasibility and cost, allocation of resources according to this hierarchy would result in a cost-effective approach to regional nonpoint pollution control.

URBAN RUNOFF MANAGEMENT PROGRAM

With this knowledge about controls and possibilities for implementation, the following steps should be taken to begin the development of an urban runoff quality control program:

- existing detention ponds throughout the region, but especially in highly developed areas should be modified to improve their performance as treatment mechanisms;
- urban runoff quality control should be coordinated with urban flooding control. This may mean expanding the responsibilities of the Urban Drainage and Flood Control District to include quality as well as quantity. Such a change may require legislative action. However, examples of quantity and quality agencies exist in other NURP projects such as Salt Lake County, Utah and Bellevue, Washington;
- Local governments should pursue implementation of drainage ordinances that incorporate water quality aspects. This may include detention basin design, percolation pits and erosion control;
- a central element of local implementation projects is interdepartmental coordination between planning, engineering and building departments. Without such coordination, no drainage improvement program will be successful; and,
- continued maintenance of drainage facilities is needed to achieve optimum performance. A detention basin will not function when accumulated sediment is not regularly removed.

The implementation of these actions will not totally control pollution from urban runoff. It will represent an initial step towards the elimination of a signficant source of pollutants.

ADDITIONAL RESEARCH NEEDS

It should be clearly stated throughout this report that not all the questions about urban runoff have been answered. In fact, the answers presented have often led to new questions. To more fully understand urban runoff, the following issues should be addressed:

- detention basin characteristics. This study was not able to explore, as completely as it wished, the ability of detention basins to remove pollutants. Various types of detention need to be tested, such as wet versus dry ponds. Outlet modifications need to be studied to determine optimum design. Size requirements and holding times should be developed into design criteria;

- impact assessment. While the DRURP has demonstrated that urban runoff causes stream standards to be violated, the actual impact on beneficial uses has not been determined. Do the elevated levels of TSS and various metals during and after a storm harm aquatic life? Are recreational and water supply uses impaired because of storm runoff? Questions such as these need to be dealt with before major implementation costs are incurred;

- point/nonpoint tradeoffs. The concept of nonpoint source control as a replacement for advance waste treatment at a domestic or industrial plant has only been touched upon in this report. This topic should continue to receive attention so that it can become a normal element of facility planning; and,

- trickle flows. It became obvious during preparation of this report that stormwater is not the only source of urban runoff. The daily flows into the region's streams from urban areas in some cases are the biggest contributors of pollutants. This may mean that point source treatment and stormwater control together may still not achieve water quality goals. This is a significant, new element of the pollution control equation. More information is needed about the quality of this trickle flow, the sources of the pollutants within this flow and any methods for control.

After three years of study and evaluation, the Denver area now has a better understanding of urban runoff. While more questions exist, enough is known to begin controlling the quality of urban runoff. The suggestions made here for implementation and study will enable the area to move one step closer to obtaining its water quality goals.

ABBREVIATIONS

ac	acre
ac-ft	acre-foot
BMP	Best Management Practice
Cd	Cadmium
°C	degrees Celcius
cfs	cubic foot per second
conc	concentration
Cu	Copper
C.V.	Coefficient of Variation
DP	Dissolved Phosphorus
D.O.	Dissolved Oxygen
DOC	Dissolved Organic Carbon
EMC	Event Mean Concentration
Fe	Iron
ft^3	cubic feet
lbs	pounds
lbs/ac	pounds per acre
lbs/ac/ro.in.	pounds per acre per runoff inch
lbs/ac/yr	pounds per acre per year
lbs/tot.A	pounds per total area
max	maximum
MGD	Million Gallons per Day
mg/L	milligrams per liter
µg/L	micrograms per liter
min	minimum
Mn	Manganese
n	number of data points
OPO4	Total Orthophosphate as Phosphorus
N02N03-N	Nitrite plus Nitrate as Nitrogen
Pb	Lead
pH	negative log of the Hydrogen ion concentration
PEI	Percent Effective Imperviousness
r	correlation coefficient
R^2	coefficient of determination
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TOC	Total Organic Carbon
TP	Total Phosphorus
TSS	Total Suspended Solids
WWTP	Wastewater Treatment Plant
Zn	Zinc

GLOSSARY

Ambient. Nonstorm periods or the periods of time surrounding storm runoff periods or events.

Antecedent Dry Days. The number of days without significant precipitation preceding a storm.

Baseflow. The streamflow that occurs without direct contribution from precipitation or effluent discharge.

Basin. The entire tract of land drained by a river or stream and its tributaries.

Best Management Practice (BMP). Any storm runoff control measure which is designed to reduce the impact of urban runoff on receiving waters. Includes both structural and nonstructural techniques such as retention ponds or erosion control ordinances.

Convective Storm. A type of storm caused by a warm and moist cell of air rising through cooler air usually due to solar heating of the local land surface. A convective storm may last from a few seconds to a few hours.

Daily Mean Streamflow. The average streamflow for a given day.

Dry-Weather Flow. The flow in a stream during a period without rainfall or snowmelt runoff. Dry-weather flow consists of baseflow and urban runoff, such as that from lawn watering.

Detention Pond. A pond or structure which controls the flow in a channel, part of which is stored temporarily. This temporary storage commonly results in suspended material settling out of suspension to become part of the bed material.

Effective Impervious Area. Impervious area which is hydraulically connected to a conveyance structure which transports runoff away from the area. An example of an effectively impervious area would be a roof which drains onto a driveway, and is connected to a street, gutter, and storm sewer.

Event Mean Concentration. The average concentration of a constituent in the total runoff from a storm. It is calculated by dividing the total constituent load by the total runoff volume.

Fecal Coliform Bacteria. Bacteria that are present in the intestine or feces of warmblooded animals. They are often used as indicators of the sanitary quality of water.

Hydrograph. Plot or graph of instantaneous streamflow versus time.

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Impervious Area. Area which does not permit infiltration of water, such as streets, sidewalks, roofs and paved parking lots.

Instantaneous Streamflow. The total flow at a cross section of a stream at a given instant in time.

Load. The total mass of a substance distributed over a surface or within a fluid medium; usually the amount of a constituent carried from a drainage basin during a given time period or in the runoff from a given storm.

Mean Annual Precipitation. The long-term average yearly precipitation at a given station.

Nonpoint Source. A source not associated with or resulting from a single location, but rather from multiple, diffuse areas of land surface or points of origin.

Nutrients. Elements or compounds particularly, nitrogen, phosphorus, or carbon which are required for growth of living organisms.

Organic Matter. Material derived from living organisms which includes complex molecules formed by partial decomposition of plant or animal matter.

Percent Effective Impervious Area (PEI). The percentage of a drainage basin which is effective impervious area.

Percolation Pit. A storm runoff control measure which consists of a hole or depression filled with course gravel or cobbles which allows percolation (or infiltration) of water. The pit is situated in permeable subsoils and is designed to filter solids from and allow rapid dissipation of stormwater.

Pervious Area. Area which allows percolation (or infiltration) of water, such as lawns or areas of porous material.

Pixel. A "picture element" which refers to the smallest measurable division of radar image used to project precipitation. A pixel is approximately one square mile.

Point Source. Associated with or resulting from a single location or point of origin.

Receiving Water. Any natural body of water in which runoff or wastewater drains into; Examples include streams, rivers, lakes, bays, or estuaries.

Runoff Load. The mass of a water-quality constituent that is transported by storm runoff exclusive of baseflow.

Runoff Period. The time period from the start of a storm when streamflow begins to exceed baseflow due to storm runoff and ending with a return to baseflow conditions.

Sediment. Any solid material that is transported by, suspended in, or deposited by water; includes chemical and biochemical precipitates and organic matter.

Storm Runoff. Storm-generated land surface runoff. Storm runoff is calculated as total streamflow minus baseflow during the runoff period.

Subbasin. A part of a drainage basin that may be treated as a unit based on drainage characteristics.

Trace Elements. Elements usually present in natural water at concentrations less than one milligram per liter.

Upslope Storm. A type of storm caused by the upward movement of a warm moisture-laden airmass over the slope of a mountain range or a cooler airmass. Upslope storms are slow in forming and usually long in duration and may last for several days.

Urban Runoff. Dry-weather flow or storm runoff or both from an urban drainage basin.

Unit-area Loading. The load of a substance per unit of land area, usually expressed for a given time period.

Water Year. A 12-month period beginning October 1 and ending the following September 30. The year designation is the same as the calender year in which it ends.

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